Signs of snow

"When might we lose the entire multiyear ice pack and transition to a seasonal ice pack?"

Sinéad Farrell
University of Maryland

by Jane Beitler

From the window of the NASA P-3 aircraft, researcher Sinéad Farrell could see the research camp on the Arctic ice pack below. The red tents of the camp specked the wind-carved snow atop the sea ice pack, where the researchers on the ground had marked out an ice survey line. The P-3 traced this line as it flew far overhead, while radar in its belly measured from the air what the people on the ground measured with shovels, rulers, and probes.

The goal was to test a way to measure the thickness of the ice cover that floats on the sea surface, and the snow laying on top of the ice, two largely missing variables in the store of observations about a warming Arctic. Researchers like Farrell wonder how soon the Arctic might lose all of its summer ice cover. They knew they needed to know more than just the surface extent of the ice to answer that question.

The world is watching

The loss of Arctic sea ice signals the warming that has been stronger in the Arctic than anywhere else on Earth. At the end of summer 2012, sea ice had shrunk to half its former extent compared to the average from 1979 to 2000, more than a million square miles less. The ice

Ice re-grows in a lead between two sea ice floes in the Beaufort Sea, Arctic Ocean, in March 2013. (Courtesy S. L. Farrell) had shrunk faster than computer climate models had predicted. While the world's citizens watched the news to see what would happen each year with sea ice, the world's scientists worked together to study the changes.

Farrell, a scientist at the University of Maryland and at the National Oceanic and Atmospheric Administration, was part of an experiment to measure ice thickness, and the depth of snow on the ice. The research camp had been established by a consortium of Danish research institutions and partnered by the U.S. Cold Regions Research and Engineering Laboratory. The aircraft she was riding was from a larger NASA mission called IceBridge because it bridges a multiyear gap in observations between two satellites. "The point of IceBridge was to continue to monitor polar regions in critical areas of change," said Farrell, who is also a member of the NASA Operation IceBridge Science Team. So the data gap is being filled with airplanes carrying arrays of sensors to measure sea ice, glaciers, and ice sheets.

Scientists knew that sea ice in the Arctic would continue to decline, but not exactly how the decline would progress. "We knew the ice pack was retreating in areas, but we didn't know how it was changing in thickness," Farrell said.

The thickness of sea ice is related to its age. "Multiyear ice is ice that survived the summer melt. It was the predominant ice type in the 1980s and 1990s," Farrell said. Ice that does not melt completely in summer thickens again during the following winter. But now sea ice in the Arctic mainly consists of new ice that froze in one season. "When might we lose the entire multiyear ice pack and transition to a seasonal ice pack?" Farrell asked.

Ice thickness matters a lot to the persistence of summer sea ice. Farrell said, "During the summer, the ice is melting and breaking up and then you have more intense storms coming through the region. The thinner the ice, we believe the more vulnerable it is to storms that break it up."

The first ICESat satellite provided some of the first remote sensing data on ice thickness, from 2003 until it stopped collecting data in 2009. "We have satellite data from the 1970s about the areal extent of the ice, but not about its volume or thickness," Farrell said. "We had some data from submarines, but no data across the entire Arctic Ocean."

On top of it all

Along with a laser altimeter to measure ice thickness, the P-3 aircraft carried an experimental snow depth radar, designed by the University of Kansas. The altimeter can measure the height of the ice sticking up above the ocean surface, which is then multiplied by a factor to calculate how deep the ice extends below the surface. Snow depth is important to this equation. "The ice is floating on the ocean, but it is weighted down by the snow accumulated on top of the ice floes," Farrell said. "It pushes them down further into the water. Knowing the weight of the snow is important to measuring the thickness of the sea ice."

Snow also plays a role in the exchange of heat between the ocean and the atmosphere. Nathan Kurtz, a research scientist on the IceBridge team at the NASA Goddard Space Flight Center, said, "If you have snow on top of sea ice, the ice doesn't grow as fast; the snow insulates it."

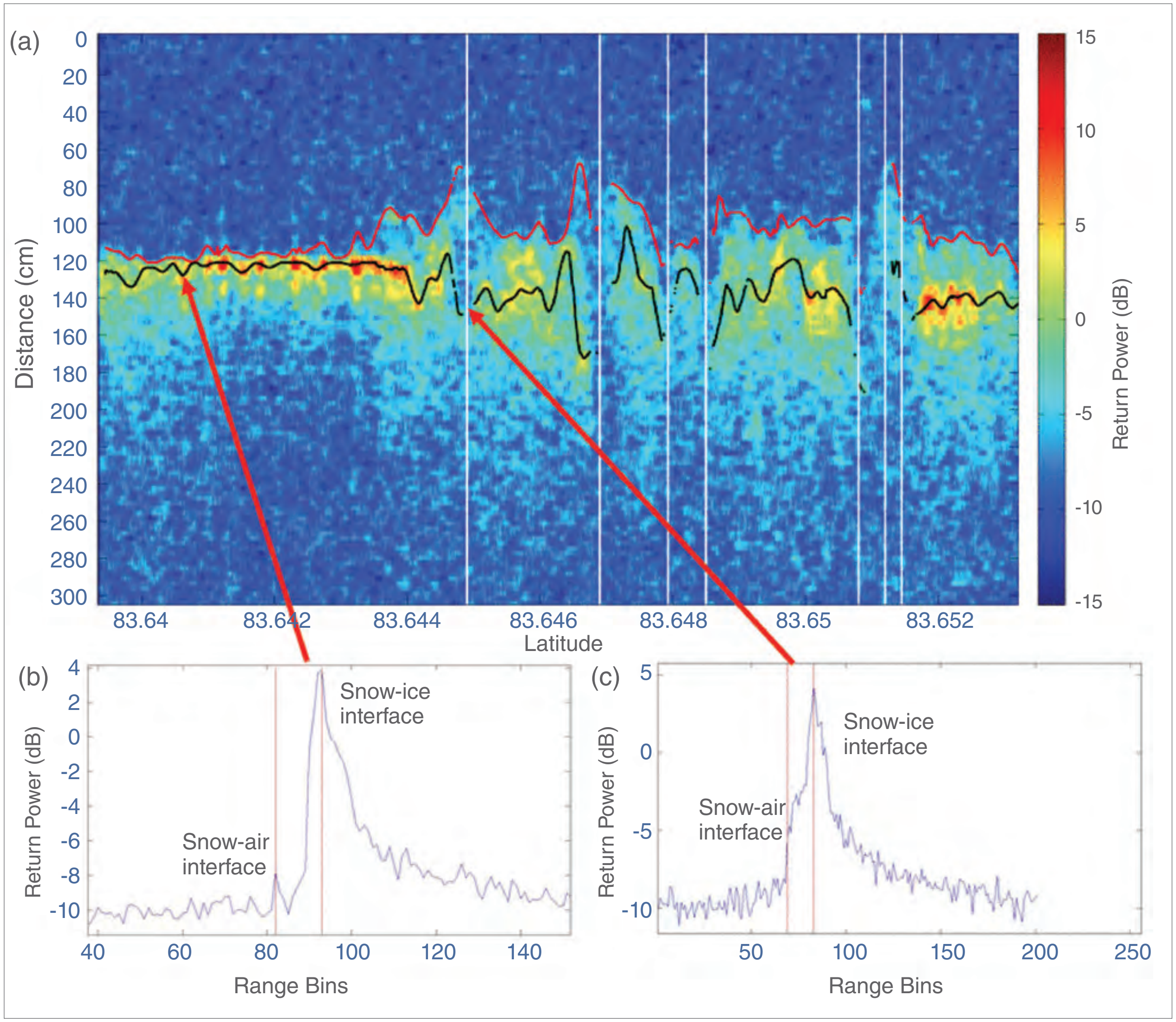
Sea ice freezes not only because the air above it is cold, but also because the ocean below it is cold.

The NASA P-3B aircraft arrives at Thule, Greenland. The aircraft carried Operation IceBridge instruments over the Arctic to study changes in sea ice, glaciers, and ice sheets. (Courtesy NASA/K. Krabill)

Open water quickly releases its heat to the air. A thick layer of snow, even on thin ice, slows down the cooling of the ocean. But with no snow and thin ice, the ocean's heat more rapidly escapes. As the ice melts, the heat equation gets more complicated. Kurtz said, "In the summer when sea ice starts to melt, snow forms melt ponds, which also affect how much radiation is being absorbed. Not a lot is known about this."

Kurtz's job is to wrangle useful measurements from the mission's several instruments. "We have a lot of data from IceBridge: laser altimeter, radar, visible images. All that is not very useable to scientists who are not experts on those instruments. So I turn it into a product, sea ice thickness and snow depth," Kurtz said.

In the case of the snow radar, this meant figuring out how to extract snow depth from the radar signal. "We knew it could work. Theoretically it should be easy, two peaks in the radar, but actually you rarely see that," he said. The signal for the top of the snow was weak, but Kurtz was



These figures illustrate the methods used to detect the depth of snow on ice using a special snow radar. Figure (a) is a processed snow radar echogram with air/snow (red) and snow/ice (black) interfaces indicated. Vertical white lines indicate where there was temporary loss of the snow radar signal along track. Figure (b) shows an individual snow radar return with clearly defined peaks in return power at the air–snow and snow–ice interfaces. Figure (c) shows an individual snow radar return with an indistinct air–snow interface. (Courtesy S. L. Farrell et al., 2012, *IEEE Transactions on Geoscience and Remote Sensing*)

able to tease out its signature, and he also figured out how to keep the data series consistent over time as the radar was improved. "It's such a hard measurement to get, but this study shows that the radar works really well. It is our best tool to measure snow depth."

Besides data from IceBridge, Kurtz also examined sea ice thickness data from Europe's Cryosat 2 satellite, ice measurements from Soviet ships, and on-the-ground snow measurements over the last fifty years. These data reinforced that snow depth and ice thickness have changed quite a bit, and helped the team set the changes in context. "In the past, multiyear ice stayed around," Kurtz said. "Now we have ice that comes and goes every year. Snow is much thinner on the ice that comes and goes, about half as deep."

Beyond the method

Proving an accurate way to measure snow depth, and using that to improve ice thickness measurements, is only step one. With Arctic sea ice continuing its downward trend, Kurtz thinks the radar would be useful to fly every year. "It is expensive to fly," he said. "But there is also talk of putting the radar on unmanned aircraft." Others are looking at how the radar might fit on a small unmanned aircraft, and be operated remotely.

Step two for Kurtz is to get the snow depth and thickness data out to other researchers studying sea ice. He has been working on what he calls "quick look" data. He said, "The campaign flies in March, April, and May. Typically we don't see any of the data for half a year after that. With the quick look, it will be out right away, so the community can use this to forecast what the sea ice will be like over the summer." He has turned the data over to the NASA National Snow and Ice Data Center Distributed Active Archive Center, where other researchers can freely access the data.

Beyond the summer, Farrell sees the data being used to improve longer-term projections of sea ice. "Another interesting goal of IceBridge is to collect data that would better inform models that predict what would happen in the future, ten to twenty years out," she said. Modelers can use the detailed data to make the mathematical equations in their models more accurate, and thus provide better predictions of sea ice in the future. Losing more of this reflective cover will allow the ocean to absorb even more of summer's heat—which will likely be passed along to Earth's climate as a whole.

"The goal now is to gather as much information as we can on the health of the ice pack," Farrell said. "The Arctic plays a key role in the overall climate system, and we need to understand the changes going on there to understand the overall climate problem."

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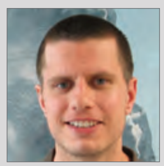
About the data used

Platforms	Douglas DC-8 and P3B-Orion aircraft	Douglas DC-8 and P3B-Orion aircraft
Sensors	Airborne Topographic Mapper (ATM)	Radar echo sounders; wide-band snow depth radar
Data sets	IceBridge ATM L1B Qfit Elevation data	IceBridge Snow Radar L1B Geolocated Radar Echo Strength Profiles
Parameters	Ice sheet and sea ice elevation	Ice sheet topography, sea ice elevation, snow depth
Data centers	NASA National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC)	NASA NSIDC DAAC

About the scientists

Sinéad Louise Farrell is an assistant research scientist at the Earth System Science Interdisciplinary Center (ESSIC) at the University of Maryland, College Park and a visiting scientist at the National Oceanic and Atmospheric Administration (NOAA). Her research interests include remote sensing of polar regions using satellite and airborne altimetry. NASA and NOAA supported her research. Read more at http://www.star.nesdis.noaa.gov/star/Farrell_S.php. (Photograph courtesy NOAA STAR)



Nathan Kurtz is a postdoctoral researcher at the NASA Goddard Space Flight Center. His research interests include sea ice thickness, snow depth mapping, laser altimetry, radar altimetry, and sea ice thermodynamics. NASA supported his research. Read more at http://neptune.gsfc.nasa.gov/csb/personnel/index.php?id=453. (Photograph courtesy NASA)

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For more information

NASA National Snow and Ice Data Center DAAC
http://nsidc.org/daac

NASA Operation IceBridge
http://www.nasa.gov/mission_pages/icebridge

IceBridge Sea Ice Freeboard, Snow Depth, and Thickness Quick Look data
http://nsidc.org/data/docs/daac/icebridge/evaluation_products/sea-ice-freeboard-snowdepth-thickness-quicklook-index.html