In the zone

“The life cycle of the snow petrel is tied to sea ice.”

Stephanie Jenouvrier
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by Laura Naranjo

During the long winters that shroud Antarctica, the ocean surface freezes over into sea ice, effectively doubling the size of the continent. In summer, this sea ice cover shrinks to about 1.2 million square miles. It is tempting to imagine the ice as a frozen wasteland, but the Southern Ocean is one of the most biologically productive zones on Earth. The ebb and flow of sea ice supports a wild array of life, from fish and seabirds to seals and whales.

That sea ice is changing. Over the past several decades, temperatures around the continent have been rising. Unlike the Arctic, which has seen a

Snow petrels wait along ice edges, ready to snatch krill or fish that come near the ocean surface. (Courtesy D. Filippi, Institut Polaire Français Paul-Émile Victor/Centre national de la recherche scientifique/Sextant Technology Ltd.)

sharp drop in summer sea ice, increased warmth has brought more subtle change to Antarctica, altering the weather and winds that govern where sea ice forms. Stephanie Jenouvrier, an ecologist with the Woods Hole Oceanographic Institution, has been studying how Antarctic seabirds adjust to the changes. Because Jenouvrier's research found that climate change could threaten many seabirds' habitats, understanding their future means understanding Antarctic sea ice. When she teamed up with sea ice researcher Julienne Stroeve to look at the birds' icy habitat, the two researchers also learned more about the limits of sea ice satellite data.

A life on the ice

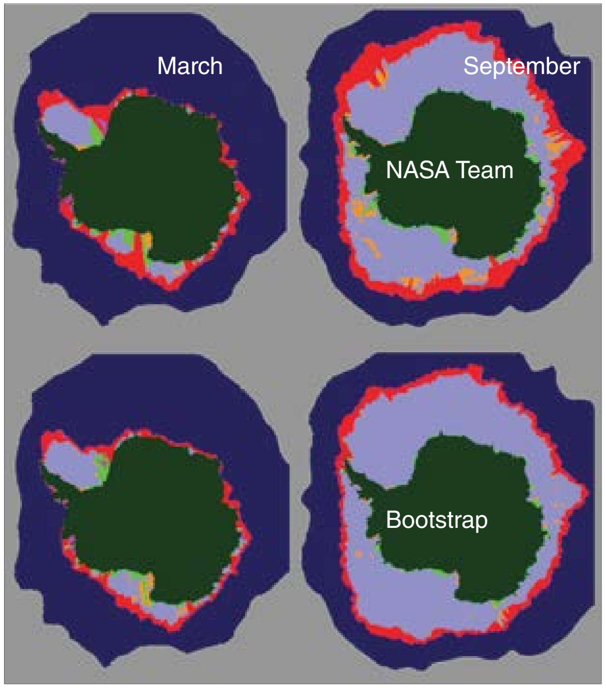
Sea ice harbors the key to South Pole survival: krill. These tiny shrimp-like creatures form the base of the Antarctic food chain. In dark winter months, krill survive by scraping algae from the underside of sea ice. During the brief summer, sea ice melts and sunlight floods the open ocean. Then the krill population booms. Swarms can cover more than 175 square miles and contain more than two million tons of krill. Seabirds like the snow petrel lurk along ice edges to snatch krill and fish swimming close to the surface. Emperor penguins dive for krill. Seals prey on krill while prowling for penguins and fish. Even massive blue whales filter and consume nearly four tons of krill daily.

For most of the Antarctic seabirds Jenouvrier studies, access to that movable feast depends on sea ice. A nearly solid cover of pack ice forms each winter from plates of ice, or floes, that slowly freeze together. Openings in pack ice are few and far between, making it difficult for seabirds to feed or seals and whales to surface for air. Further out, however, lies a broad transition between pack ice and open water. This region, called the Marginal Ice Zone (MIZ), is susceptible to winds and waves that fracture floes and prevent the ocean from freezing over. During the spring thaw, the MIZ temporarily expands slightly as the pack ice breaks into floes again.

The icebreaker *Aurora Australis* churns through pack ice surrounding East Antarctica. (Courtesy A. O'Connor)

In fact, the sea ice cover is almost constantly changing. Pack ice tends to grow and shrink consistently over the course of seasons, but the MIZ changes within hours or days, depending on weather and wind patterns. Additionally, sea ice around the Antarctic continent varies by region. For instance, despite recent record high ice extents around most of Antarctica, sea ice extent in the Bellingshausen and Amundsen Seas has decreased. Scientists suspect that strong winds are partly to blame, compacting ice against the coast. A compacted ice cover means fewer open areas where seabirds can feed, especially during winter when pack ice pushes the MIZ farthest from the coast. If this regional trend continues, seabird populations in this region may begin to decline.

Krill and seabird survival depends on a balance of pack ice and marginal ice. High pack ice extent nurtures a robust krill population, but can



This data image shows samples of sea ice classification from March (left) and September (right) 2013. The Marginal Ice Zone (red) represents sea ice concentration between 15 and 80 percent. Pack ice (light purple) shows greater than 80 percent sea ice concentration. Orange regions indicate broken ice areas; pink areas are open water; light green areas are potential coastal polynyas, or areas of open water. Dark blue represents open ocean. (Courtesy J. Stroeve, et al., 2016, *The Cryosphere Discussions*)

prevent seabirds from feeding on much of that feast. The Antarctic Peninsula has the opposite problem. Along the Peninsula, warm temperatures have led to lower winter sea ice extents, diminishing the amount of krill and forcing seabirds to compete for less food. Jenouvrier had studied how such changes affected penguins, and shifted to study snow petrels, another seabird that spends its entire life in Antarctica. Although snow petrels are not currently threatened or endangered, they will likely respond to changes in sea ice conditions that reduce krill abundance.

Snow petrels are the size of a pigeon, snowy white except for black eyes and beak. "The life cycle of the snow petrel is tied to sea ice," Jenouvrier said. "Sea ice does not affect their survival directly. It affects their ability to successfully breed." To breed, females must feed well during the previous winter. "The size and weight of a female before breeding will influence whether she will be able to raise a chick during the summer," Jenouvrier said. She hoped that mapping MIZ extent and variability would reveal correlations with snow petrel breeding success.

Defining the marginal ice zone

Stroeve, a scientist at the National Snow and Ice Data Center, works with the longest sea ice satellite records, dating to 1978. The data come from the Scanning Multichannel Microwave Radiometer (SMMR) and the Special Sensor Microwave/Imager (SSM/I) instruments. Researchers can use these data to see how overall ice extent is changing around Antarctica. However, observing how pack ice and the MIZ are changing is more complicated, so Stroeve wanted to explore whether satellite data could help.

Stroeve uses computer algorithms to sort ice types, distinguish land ice from sea ice, and identify errors. Pack ice is defined as ice covering at least 80 percent of the ocean surface; ice cover of less than 15 percent defines the MIZ. But parsing pack ice from the MIZ was tricky. "I noticed that the results depended on which algorithm you used," she said.

Using more than one algorithm can help scientists root out trends, especially when studying daily, seasonal, and annual variations in Antarctic sea ice. Scientists frequently use one of two standard algorithms for data from SMMR and SSM/I, called NASA Team and Bootstrap. Each algorithm focuses on particular aspects of sea ice study. Jenouvrier said, "We know that NASA Team and Bootstrap algorithms give very different results, so we wanted to explore both." Both captured the total sea ice extent, as well as the timing of seasonal sea ice growth and retreat, but the MIZ in the NASA Team algorithm was twice as large the MIZ in the Bootstrap algorithm, when averaged over the entire year.

So the researchers and their colleagues compared the results to snow petrel records, pulling data from a French science station in East Antarctica. This long-term data set included the number of snow petrel chicks hatched from 1979 through 2014. Comparing the sea ice and snow petrel data confirmed that extensive winter pack ice impaired access to krill, which decreased snow petrel breeding success.

Jenouvrier said, "Krill are very dependent on sea ice. When you have years with higher winter sea ice you may have years with higher recruitment of krill." Yet the pervasive ice pack that fostered krill proved stressful for breeding snow petrels. Stroeve said, "When you look at winter ice conditions, we do notice that their breeding success reduced when there was a lot more consolidated winter ice, compared to if it had more broken MIZ ice." So if changes in the MIZ did not drive snow petrel breeding success, what did?

Location, location, location

Finding the answer may require zooming in to study how the mix of pack ice and MIZ is changing on a regional level. "Regional variations in sea ice will impact the bird populations in various areas of Antarctica differently," Stroeve said. The MIZ is already strongly influenced by wind and ocean conditions, which vary around the continent and are changing at different rates, and will be more sensitive to further changes, such as ice compaction from wind or warming ocean currents.

Studying the usefulness of each algorithm is only a first step in Jenouvrier's research on snow petrels. Jenouvrier said, "Imagine that you're an ecologist and you did not have a colleague like Julienne and you did not know the difference between the algorithms. We now encourage ecologists to use several algorithms, because it is very hard to say which one is the most valuable, especially for ecological applications."

Jenouvrier and Stroeve will continue studying the effects of sea ice changes on Antarctic seabirds. "One of the things we're going to do is validation with visible imagery to get a better handle on which algorithm to trust, in terms of these types of ecological studies," Stroeve said. The team will also compare their results with climate models to see how sea ice changes and variability might impact bird species in the future. For now, snow petrels continue to thrive as they flit, feed, nest, and breed against a backdrop of snow and ice.

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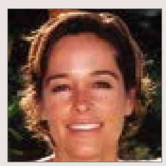
About the remote sensing data

Satellites	Defense Meteorological Satellite Program (DMSP) F8, F11, F13, and F17, and Nimbus-7
Sensors	Scanning Multichannel Microwave Radiometer (SMMR) Special Sensor Microwave/Imager (SSM/I) Special Sensor Microwave Imager/Sounder (SSMIS)
Data sets	Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data, Version 1 Bootstrap Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS, Version 2
Resolution	25 x 25 kilometer
Parameter	Sea ice concentration
DAAC	NASA National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC)

About the scientists

Stephanie Jenouvrier is an associate scientist at the Woods Hole Oceanographic Institution (WHOI). Her research focuses on understanding and predicting the effect of climate change on seabird dynamics and ecology, especially in the Southern Ocean. NASA supported her research. Read more at https://goo.gl/LyT4fc. (Photograph courtesy S. Jenouvrier, WHOI)



Julienne Stroeve is a senior research scientist at the National Snow and Ice Data Center (NSIDC). She studies Arctic and Antarctic sea ice using remote sensing in the visible, infrared, and microwave wavelengths. NASA supported her research. Read more at https://goo.gl/l3fnZI. (Photograph courtesy NSIDC)

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For more information

NASA National Snow and Ice Data Center Distributed Active Archive Center (NSIDC DAAC)
http://nsidc.org/daac

Scanning Multichannel Microwave Radiometer (SMMR) and Special Sensor Microwave/Imager (SSM/I) – Special Sensor Microwave Imager/Sounder (SSMIS) Data
https://nsidc.org/data/smmr_ssmi