# 2015 Annual Report

# National Snow and Ice Data Center

*Advancing Knowledge of Earth's Frozen Regions*

*Cover: Fog settles in Andvord Bay on the west coast of the Antarctic Peninsula.*

*Credit: E. Pettit, University of Alaska, Fairbanks*

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# Director's Overview

## Our Mission

The mission of the National Snow and Ice Data Center (NSIDC) is to improve our understanding of the Earth's frozen realms. This includes our planet's floating sea ice cover, lake ice, glaciers, ice sheets, snow cover and frozen ground, collectively known as the cryosphere. NSIDC advances its mission through:

- Managing, distributing and stewarding cryospheric and related climate data collected from Earth orbiting satellites, aircraft missions and surface observations
- Facilitating the collection, preservation, exchange, and use of local observations and knowledge of the Arctic
- Conducting research addressing all major elements of the cryosphere; this research has increasingly focused on understanding how and why the cryosphere is changing and the implications of these changes
- Conducting informatics research aimed at finding better ways to discover, integrate and distill the vast and growing volume of cryospheric and climate data
- Educating the public about the cryosphere, the changes that are being observed, and their implications

The National Snow and Ice Data Center is part of the Cooperative Institute for Research in Environmental Sciences, at the University of Colorado Boulder.

> NSIDC is finding more efficient ways of conducting its work, including capitalizing on synergies between different projects and embracing a more flexible and responsive team-oriented approach to software development.

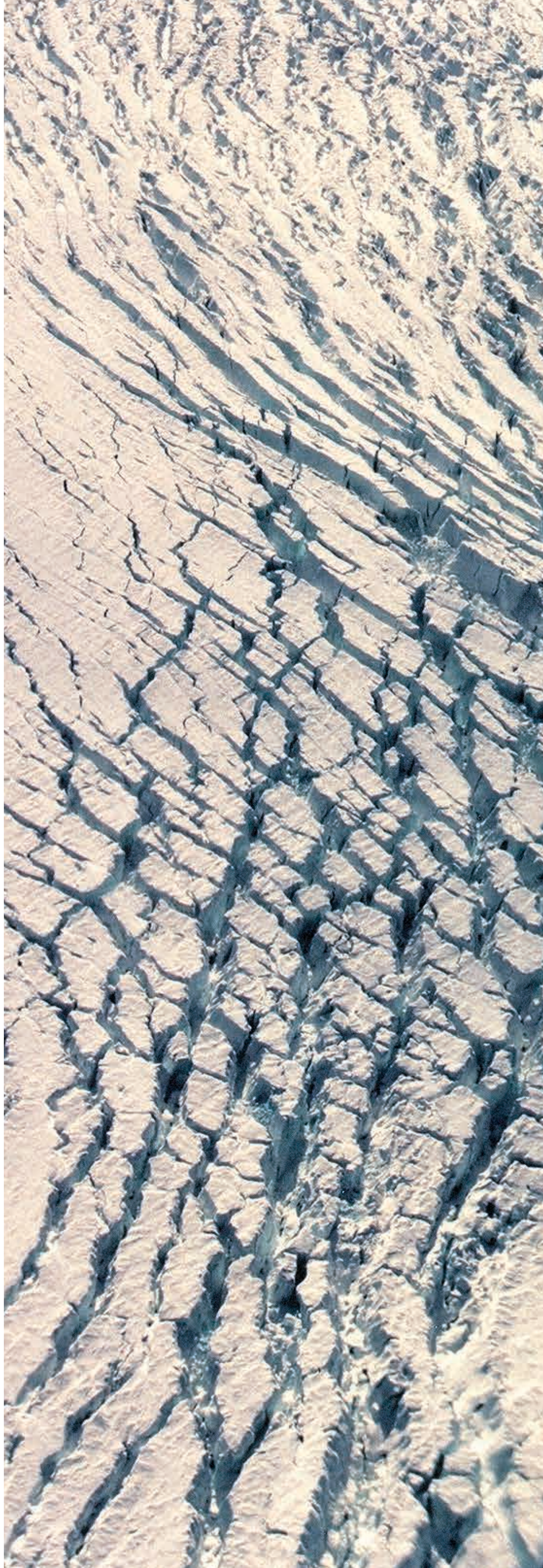
NSIDC makes hundreds of scientific data sets accessible to researchers around the world, ranging from small text files to terabytes of remote sensing data from the National Aeronautics and Space Administration (NASA) Earth Observing System satellite program and other sources. Our data managers, technical writers and scientific programmers operate in teams to create or publish data sets, working closely with data providers and users to understand their needs and to offer documentation, tools, and formats that support scientific research. NSIDC also works to ensure that data and metadata (data describing the data) are continually preserved and will be accessible for the long term, so that researchers can study polar climates over long periods. Together, these practices ensure the physical and scientific integrity of the data we manage and disseminate. We manage data under sponsorship from NASA, the National Oceanic and Atmospheric Administration (NOAA), and the National Science Foundation (NSF).

Major areas of research at NSIDC include:

- Processes driving the observed downward trend in Arctic sea ice extent and the environmental and societal consequences of this ice loss both within and beyond the Arctic
- The behavior of the Greenland and Antarctic ice sheets, and their contributions to sea level rise
- Links between hydrologic changes and land surface phenology in Greenland

- The behavior of Himalayan glaciers and impacts on water resources
- Forecasting stream flow in the American west
- Developing cyberinfrastructure for the Arctic social sciences and physical sciences
- Developing consistent global and continental scale Earth system data records
- Creating a global inventory of the world's glaciers
- Assessing changes in Earth's permafrost and their implications
- Forecasting Arctic sea ice conditions
- Developing alternative database structures to enable investigators to more efficiently search through vast data volumes to answer science questions
- Developing services to making NSIDC data more visible and useful to more researchers
- New directions in data stewardship
- Enhancing data discovery through semantic interoperability

A continued strength of NSIDC is synergy between its environmental and informatics research and data management. Our in-house scientists consult in creating data products, answer questions from data users, and in some cases produce new data sets distributed by NSIDC. NSIDC's education and outreach efforts are wide ranging. NSIDC scientists are in high demand by the media to lend their expertise on environmental issues involving cryospheric change. *Arctic Sea ice News and Analysis* (http://nsidc.org/arcticseaicenews), the most popular web page at NSIDC, provides daily updates of Arctic sea ice extent along with scientific analysis of evolving conditions that is both accurate but accessible to a wide audience. *Icelights* (http://nsidc.org/icelights) provides detailed information on ice and climate topics to complement Sea Ice News and Analysis. *About the Cryoshere* (http://nsidc.org/cryosphere) provides a range of information about Earth's snow and ice, from comprehensive sections to quick facts on popular snow and ice topics. *Greenland Ice Sheet Today* (http://nsidc.org/greenland-today) focuses on assessing summer surface melt over the ice sheet. Images are updated daily, and we post analysis periodically as conditions warrant. *Satellite Observations of Arctic Change* (http://nsidc.org/soac/freeze-thaw.html) expose NASA satellite data in the form of maps that illustrate changes today taking place over time.



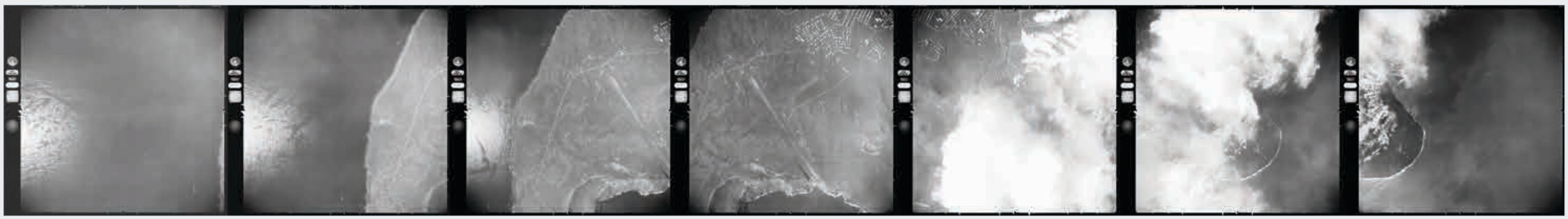
# Highlights of 2015

This annual report contains publications, projects and financials for fiscal year 2015. NSIDC Monthly Highlights (http://nsidc.org/monthlyhighlights/) illustrates the breadth of work at the Center, including how we are addressing challenges in data management, research on the cryosphere and the changes that are taking place, and how we are developing innovative ways to add value for our data and information users.

However, words and pictures are ineffective in conveying the pride, spirit of teamwork and willingness to adapt to change that characterize the employees of NSIDC. In response to an increasingly challenging funding environment, NSIDC strives to find more efficient ways of operating, including capitalizing on synergies between different projects, embracing a flexible and responsive team oriented approach to promote better coordination and communication between the different functional groups of the center. NSIDC is always learning, and is constantly trying to improve itself to better serve the global community.

# 2015 Monthly Highlights

## Ninety-nine canisters of film on the wall



*This sequence of images captures a flight line over Iceland on one of the digitized canisters. Credit: NSIDC*

In 1996, NSIDC received ninety-nine canisters of ungainly film rolls. Each stored hundreds of photographs, most of sea ice, but also glaciers, land, snow cover, and coastlines dating as far back as 1962. The photographs, part of the U.S. Navy-initiated Project Birdseye, offered never before seen images of the Arctic at the height of the Cold War, when the area had potential to become a theater of operations. Today, this abandoned military research operation might extend valuable knowledge to scientists studying changes in the Arctic.

"We don't have a lot of Arctic Ocean data that starts in the 1960s," said Ann Windnagel, project manager at NSIDC, "because the satellite record doesn't start for another decade." The long and uncertain journey of these ninety-nine canisters epitomizes the difficulty of reviving old data. With technology progressing at an increasing pace, information is in danger of getting left behind. "Birdseye is a data rescue story," said Florence Fetterer, who oversees NOAA programs and projects at NSIDC. "It's important to preserve material like this because it's a record of an ice cover that's quickly disappearing." NSIDC became a steward of this data almost twenty years ago; can NSIDC not only restore the project's data, but actually make it accessible to the public?

Project Birdseye aimed to understand the Arctic Ocean, and in particular, sea ice. "The Navy was way out ahead of the game in terms of researching the Arctic Ocean," Fetterer said. Unlike surface ships, submarines had the then-unique ability to

*Opposite: Wind-eroded crevasses on the Scar Inlet ice shelf, northern Antarctic Peninsula. Dark areas are wind-blown dirt from adjacent mountains. Larissa project, April, 2013. Credit: T. Scambos, NSIDC*


A picture of a Birdseye squadron from 1962. Credit: U.S. Navy

operate and take measurements regardless of sea ice cover, weather conditions, and time of year. Much of the ocean basin could be comprehensively investigated. With Soviet nuclear submarines capable of targeting US coastlines, the Navy needed to know how to operate in the Arctic. It meant knowing how to predict ice behavior, and where the ice might be thin enough for a submarine to surface. Project Birdseye lasted from 1962 to the mid 1980s, generating important weather reports, aerial photographs, and other data. However, the photographs remained as the sole comprehensive data of the project. Much from the naval research operation has been destroyed or lost. "Other aircraft instrument data never made it out," Windnagel said. The Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire stored the surviving ninety-nine canisters until 1996 when NSIDC petitioned for their stewardship. "It was an act of faith to take them," Fetterer said. "These canisters are huge." They measure at a foot tall and six inches in diameter. Storing them was just one of the challenges. "Would we ever publish them; what's the point?" Fetterer asked. The ninety-nine canisters sat on shelves in an interior room at NSIDC for years, then were moved to an adjacent building, only to come back once NSIDC and its NOAA data center partner received grant money to scan the images. And so, ten years after they arrived, off the ninety-nine canisters went back east to a lab with the proper machines to handle the material. Only seven of the ninety-nine got scanned. Funding died. The canisters traveled back onto NSIDC shelves to await future opportunities. In the meantime, with images digitized, another issue developed. No documentation accompanied the photographs. How would the data be organized? What could the data offer? "Getting it online and getting it fully documented, meant the project got pushed back," Fetterer said. "Other things took priority."

That is until Brian Zelip, a graduate student at the Graduate School of Library and Information Science at Illinois University, took interest. He managed to find a lot of material that NSIDC simply did not have. Working with the Matthew Fontaine Maury Oceanographic Library in Mississippi, Zelip found seventy-two reports describing the missions, historical photos of the crew and airplanes to give a human component to Project Birdseye. "Putting the pieces together, the history, that's exciting," Windnagel said. "Seeing that some of the reports matched up to the photographs we had was a big 'Aha' moment." Now the images could be given context.

## What now?

With summer sea ice receding, the Arctic yet again is an area of interest. Bordering the United States, Canada, Nordic countries, and Russia, the Arctic's potential for international dispute continues. New shipping lanes and fishing waters have already been tested. Further into the Arctic Ocean national boundaries blur. Containing a significant portion of the world's undiscovered oil and untapped gas, who owns what may become an increasingly sensitive issue. Having knowledge of how the Arctic functions may be key to successful diplomacy, but could Project Birdseye offer any scientific value to the photographs? And really, do we even know that yet?

Project Birdseye captures one of the earliest large-scale photographic records of sea ice, but someone has to unravel the meaning behind the images. "We put a lot of the pieces of the data out there," Windnagel said. "But we didn't analyze it." That is for someone else to do. "It's not like a computer that can just digest numbers. Someone has to look at these photographs," Windnagel added. "The pictures are great, though limited because they're just flight lines." A flight line illustrates the path of an airplane with photography below, unlike a satellite that offers a more complete record from multiple orbits. Nine flights a year for roughly twenty years provides some clues across the Arctic. "Since the flight tracks and altitude varied by mission, the images offer more of a spatial and temporal snapshot, a slice of the Arctic," Windnagel said.

*The attack submarine USS New Mexico (SSN 779) surfaces at Ice Camp Nautilus in the Arctic Ocean during Ice Exercise (ICEX) 2014 on March 22, 2014. ICEX tested submarine operations in the Arctic. Credit: J. Davies, U.S. Navy*

"Though we didn't get everything online, there now is a substantial record so that those that come after us, will at least know what it was and where to pick up the pieces," Fetterer said. Now, almost twenty years later, 1,752 images from seven of the ninety-nine canisters are available online at NSIDC. Meanwhile, ninety-two canisters hold thousands of photographs of the Arctic yet to be seen.

## Breaking new ground

About 97 percent of Earth's water swirls on the surface in oceans and rivers, and another 2 percent is frozen in glaciers and ice sheets. Only a small percentage of Earth's water moistens the soil—1 percent at the most. This small amount underground, however, plays a surprisingly large role in processes aboveground. Soil moisture helps grow the crops people eat. Moisture in the soil helps determine whether heavy rains will result in flooding. And soil moisture affects the heat exchange between ground and atmosphere, influencing cloud formation and weather. Historically, scientists have used soil gauges to record soil moisture, but that tends to be labor-intensive, and gauge networks often only cover small areas. Now, the best way to study soil may be from the sky. On January 31, 2015, NASA launched the Soil Moisture Active Passive (SMAP) observatory, which will produce global maps of soil moisture.

*Marisa Griffin, agriculture research coordinator in crop and soil science uses a device (TDR) to measure moisture in the turf at the UGA College of Agriculture in Griffin, Ga. Credit: John Amis*

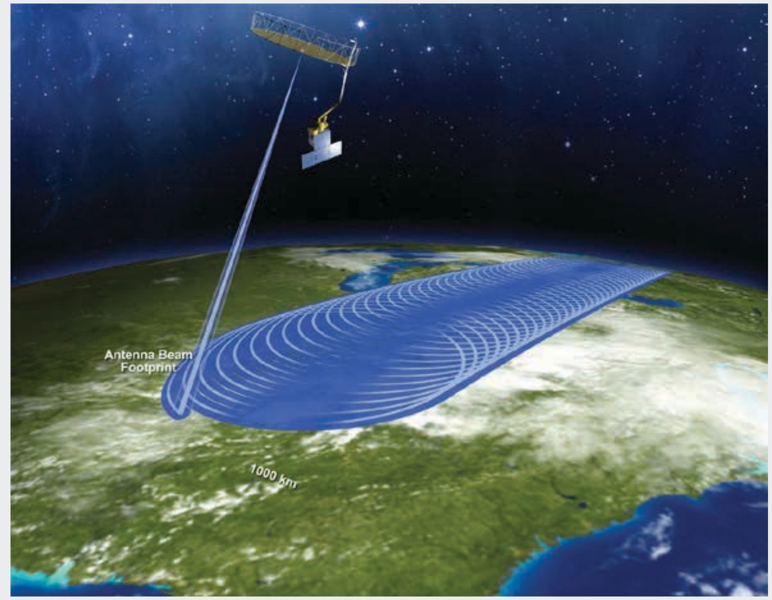
### Early adopters

The launch was only one step in an already groundbreaking mission. For the first time, a NASA mission has coordinated with a new segment of potential data users long before the satellite even launched. "Historically, NASA missions have been about research and climate studies," said Amanda Leon, SMAP data management lead at NSIDC Distributed Active Archive Center (DAAC). "But there are so many applications that will benefit from SMAP data, such as weather forecasting, agriculture, and human health." So NASA initiated an Early Adopter program, which is a part of the SMAP Applications Working Group. The program is composed of organizations and individuals who engage in pre-launch efforts to enable faster integration of SMAP data after launch. In return, the SMAP mission provides the Early Adopters with simulated SMAP data products, tailored support, and participation in data product discussions.

Part of the reason NASA is trying to engage users early on is because of the broad range of applications SMAP data can be used for. "The Early Adopters include everything from John Deere to an insurance agency in the United Kingdom," said Leon. "We've been able to talk with them and understand how they hope to use the data and that insight is driving the support and services developed by the DAAC." Leon has spent the past several years coordinating between Early Adopters and the mission to ensure data will be available in formats needed by these unique communities.

As one of the DAACs receiving SMAP data, NSIDC is heavily involved in the entire process. Although NSIDC DAAC typically handles snow and ice products, it was chosen for the SMAP mission because of previous success in supporting and distributing soil moisture data from the Advanced Microwave Scanning Radiometer – EOS (AMSR-E) instrument on the NASA Aqua satellite. Added value Many of these Early Adopters have never used satellite data, so Leon and the SMAP team at NSIDC DAAC have worked with them to understand their current methods for assimilating data into their applications. As a result, NASA has endorsed several formats not typically distributed in its standard product lineup, but that are commonly used by the hydrology community. Some of the additional formats include GeoTIFF, or TIFF files containing georeferencing information, and Keyhole Markup Language (KML) files, which are designed for use with Google Earth.

In addition to providing new data formats, Leon's goal has been to make sure that NSIDC DAAC is properly documenting the data sets for users, as well as developing the services and interfaces that will be easiest for them to use. "The value that the NASA DAACs provide is to serve as a bridge between the data users and the missions," Leon said. "We want to understand what users are trying to do and how the data can be more broadly used, and we're trying provide some value beyond just making the data available."




*This artist rendition shows the Soil Moisture Active Passive (SMAP) mission instrument and coverage footprint. A giant rotating reflector, attached to a boom, will gather soil moisture data as the satellite orbits Earth, mapping the entire globe about every three days.*

*Credit: NASA*

## Serving up soil moisture

NSIDC DAAC ingested the first data a mere two weeks after launch, but the mission still needs to complete a three-month instrument orbit check, followed by a three-month period during which the data are calibrated against ground measurements to validate the quality. The NASA Alaska Satellite Facility DAAC will archive and distribute Level 1 radar data, and NSIDC DAAC will distribute Level 1 radiometer data as well as all Level 2 through Level 4 products, including a soil freeze-thaw product. The mission plans to release a beta version of the Level 1 products to the public in late July 2015, according to Leon. Early Adopters, however, are already testing with the simulated SMAP products. "The idea is that they can become familiar with the structure of the data and start looking at how to integrate it into their applications," Leon said. "It will allow for quicker integration of SMAP data as soon as it's available." Because of this unique approach, the DAACs will know exactly what users need, and users can hit the ground running with SMAP.

*Muskoxen are large bovines that live in Greenland and the Canadian Arctic. Credit: Wikipedia*

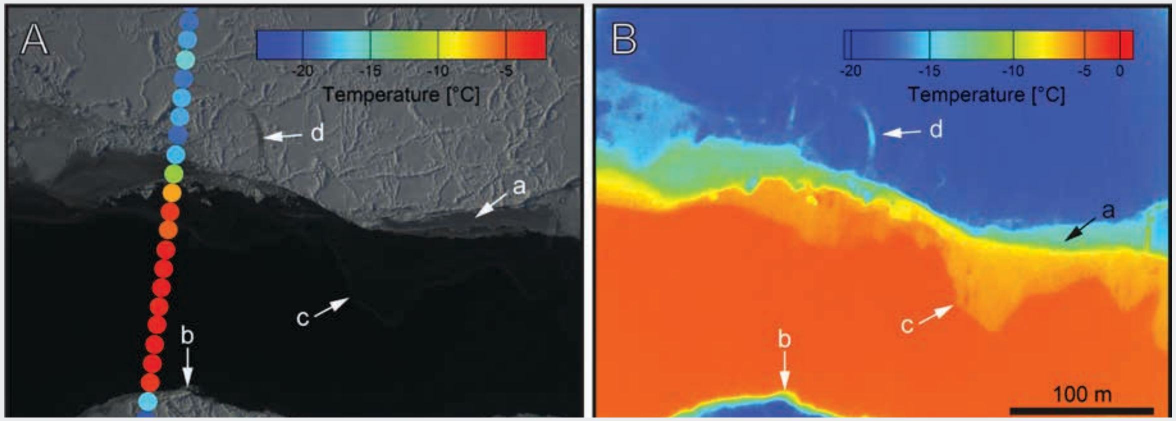
## Surveillance tech reveals greater ice sheet detail, and more

The National Snow and Ice Data Center (NSIDC) is well known for its data on frozen parts of the Earth. But soon, it will have data on something more warm-blooded.

Scientists on a mission to measure Greenland's melting ice sheet have been exploring heat-seeking cameras typically used by the police, the military, and pilots. They were using it to scrutinize Greenland's land and sea ice, but stumbled on a rather unusual use for the science instrument.

On May 12, 2015, scientists from NASA Operation IceBridge were flying over the eastern coast of Greenland—one of many flights to measure the island's ice thickness. The researchers were also testing the Forward Looking Infrared (FLIR) camera that had just been added to their suite of instruments. The FLIR Cam's thermal imaging helps map very thin ice that other sensors haven't been able to see. En route to their next transect, they spotted a herd of large, furry animals down below.

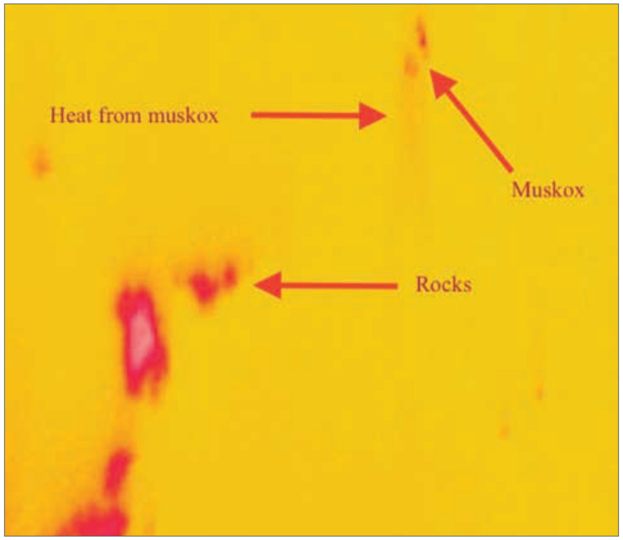
"We're flying over some muskoxen right now!" the C-130 pilots announced over the aircraft intercom to the team hunkered in the plane's cargo area. Muskoxen are large bovines that live in Greenland and the Canadian Arctic. They have large, thick coats and weigh from 350 to 600 pounds. Remote sensing expert Jim Yungel sat in the cargo with other scientists. "We had a limited view of the outside world," he said. "The back of a C-130 has very few windows." So they scrambled to peer at a camera, called the Continuous Airborne Mapping By Optical Translator (CAMBOT), and saw an image of the muskoxen and their hoof prints in the snow.




*FLIR cameras help scientists map thinner ice that can't be seen by many sensors. Image A is from the Digital Mapping System (DMS) camera, while image B is a FLIR image of the same area. Label a) shows thermal imaging revealing thickness changes with different temperatures. Label b) shows temperature gradients across edge of lead. Label c) reveals very thin ice that is difficult to identify in the DMS image and can lead to a bias in ice thickness estimates. Label d) shows small scale features can be resolved with this camera.*

*Credit: NASA IceBridge*


*Muskoxen are seen in the upper right edge of the photo with their hoof prints trailing behind. This image was taken by the Continuous Airborne Mapping By Optical Translator (CAMBOT). Credit: NASA IceBridge*




*This image shows the combined FLIR and CAMBOT images. Red blurs show heat signatures left by the muskoxen. The red spots on the left and lower left show heat signatures from rocks. Credit: NASA IceBridge*

"Just for the heck of it, another scientist checked the FLIR Cam," Yungel said.

Alexey Chibisov, an instrumentation engineer, first saw the heat signatures of some rocks that the muskoxen had passed. Then the scientists noticed a blur where the animals should have been.

"We paired up the CAMBOT image and the FLIR Cam image and scaled it up," Yungel said. "The red blur was residual heat from where the muskoxen were walking through the snow. I included the images in the Situation Report that we write after each flight, and many folks seem interested in this unusual use of the science instrumentation."

Police departments and the military often use FLIR cameras when they are looking for a lost child, or someone who is trying to hide. Pilots also use FLIR cameras to steer their aircraft at night or in thick fog. The camera senses infrared radiation emitted by a heat source and creates a "picture" of those radiation signatures. Living and nonliving things all have radiation signatures, so a FLIR image can paint an outline of a scene using these signatures.

"It has shown great potential for scientific land and sea ice use," Yungel said. "I don't know what kind of information can be gleaned from the muskox images, but a lot of folks in Greenland study Arctic wildlife. There's a lot of potential in that too."

Operation IceBridge's FLIR data will be used with other mission data to create a comprehensive map of the Greenland ice sheet's thicknesses. However, FLIR data will also be available as a separate data set. All IceBridge data are archived and distributed by NSIDC. Yungel will be one of the first to pore through the images. "I'm looking forward to discovering some more unusual targets," he said.

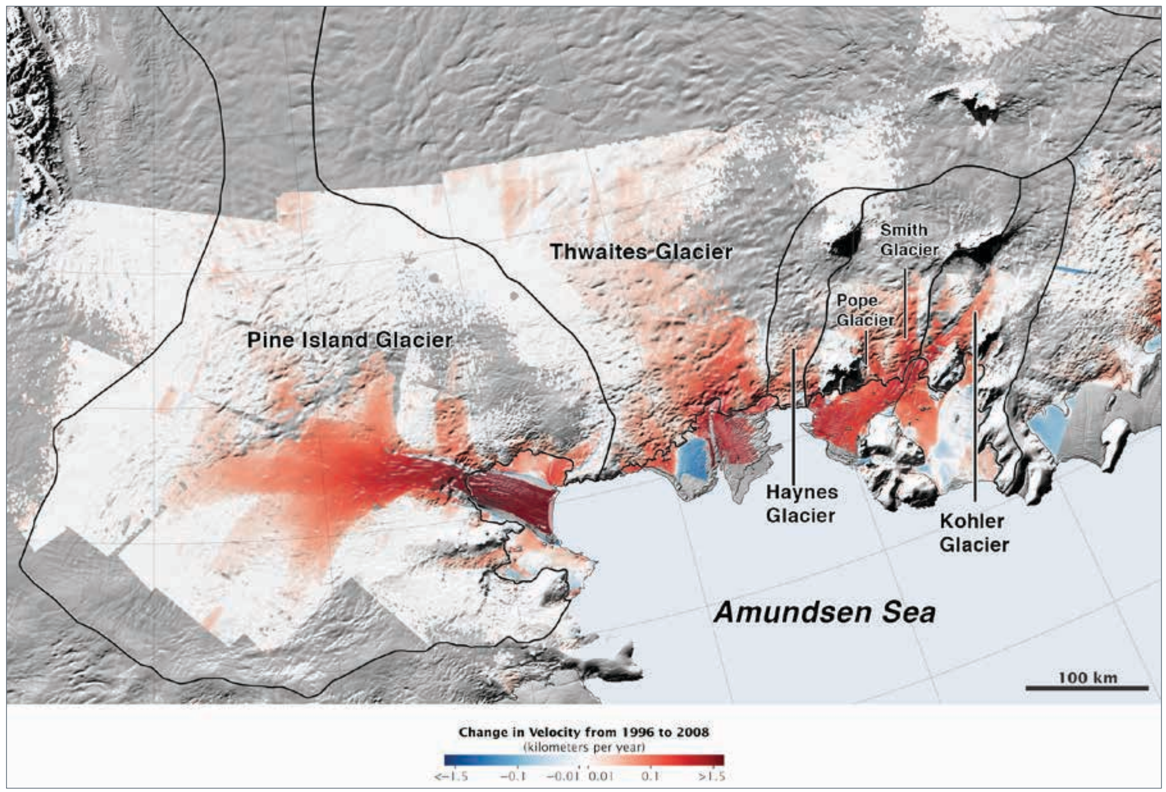
## Paving the runway for a runaway

The broad tongue of Thwaites Glacier spreads its ice onto the cold Amundsen Sea, forming a floating ice shelf. But warm waters and stronger winds are loosening the glacier's hold on the continent. Although the Amundsen Sea glaciers make up only a fraction of the whole West Antarctic Ice Sheet (WAIS), the region contains enough ice to raise global sea levels by 1.2 meters (4 feet).

Massive portions of the WAIS dip below sea level. In theory, this inland slope inherently destabilizes the ice sheet and may lead to rapid disintegration. NSIDC scientist Ted Scambos thinks that Thwaites Glacier—having the deepest ice at the center of the WAIS—is particularly vulnerable to a runaway, when a glacier lifts off the continent and slides into the ocean.

## X-ray vision

NASA Operation IceBridge and other missions have pierced through Antarctica's two-mile thick ice, to unveil its bedrock topography where




*These fast moving glaciers are considered the weak underbelly of the West Antarctic Ice Sheet (WAIS). Satellite observations show calculated changes in ice flow between 1996 and 2008. Red is accelerating; blue is slowing. Changes extend far inland. Thwaites glacier, in particular, could pave the path for a large retreat of the WAIS. Credit: NASA*

*NASA Operation IceBridge surveys Thwaites Glacier in West Antarctica.*

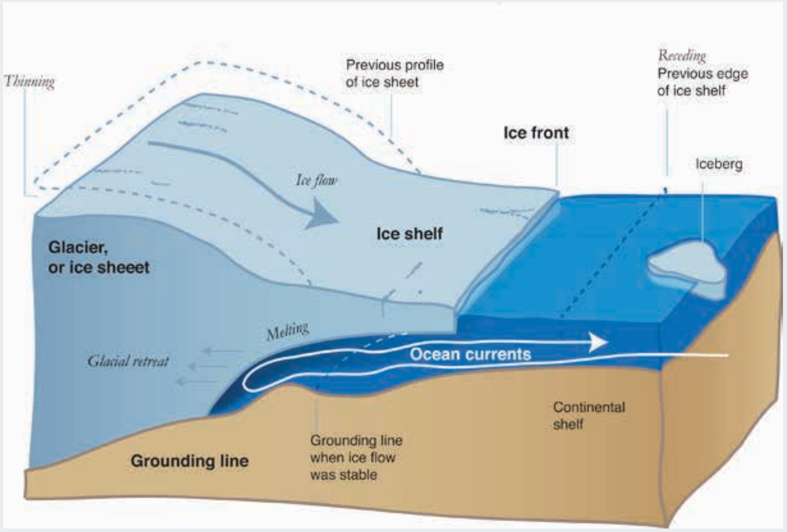
*Credit: Jim Yungel, NASA*

extensive sections drop up to a mile and a half below sea level. Warming waters grind away at the ice along its grounding lines, where ice flows off the continent and begins to float. "You really chew away at the ice here," Scambos said. "The rate of melting can be 100 feet per year. So this destabilizes the contact area." If the ice shelf thins enough, inland ice may begin to float, allowing warm water into the new gap, easing friction against the continent. "Then the glacier could lift off," Scambos said. "And this whole ice section of ice, the size of Colorado, could runaway very quickly. Once it gets past a certain point, there's a positive feedback and it gets out of control. At that point, it can't be stopped." For now, the floating ice sheet dams inland glaciers. Still, the big ice mass that is piled on top of the continent wants to push out toward the ocean.

## How did we get here?

Climate change is impacting Antarctica on many levels: on the ice, in the ocean, and on the winds driving the ocean. Warmer temperatures in the ocean's middle layers are part of the concern, but a bigger issue is shifting winds that have occurred in the past 40 years. These winds are driving deep ocean layers onto the continental shelf. The warm water pulses—which have been around, but never with this much frequency—weaken the brakes from the ice shelves since their underbelly gets eaten away.

Faster winds circling the continent push deeper warm waters toward the coast in the Amundsen Sea. As a huge, high continent that sticks out, Antarctica stabilizes the circular, westerly-wind




*When bedrock slopes inward toward the continent, warm, deep ocean water can flow downward under the ice shelf, chewing away at the grounding line. Melting can be as much as 20 to 50 meters of ice thickness each year. As the glacier's base recedes, the brakes holding the continental ice ease up and the glaciers feeding the ice shelf accelerate, and thus further thin and recede the ice sheet.*

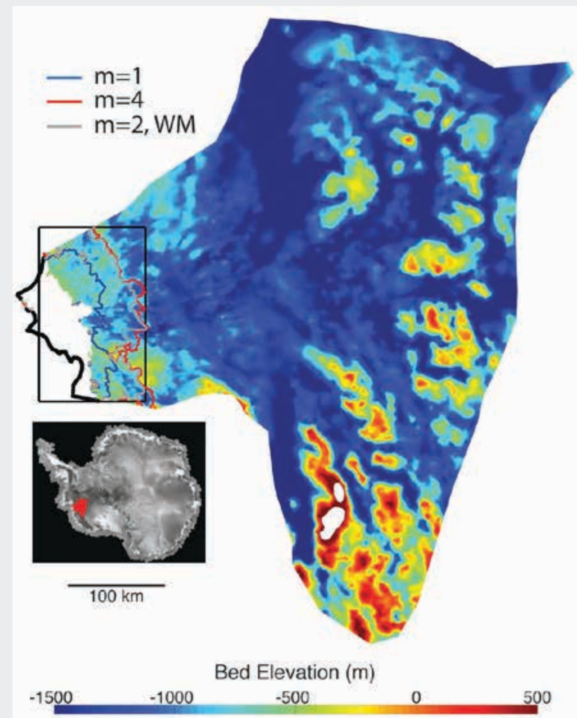
*Credit: NSIDC, NASA*

pattern. As the mid-latitudes get warmer, the winds get squeezed against this immoveable land mass. The bottleneck-effect strengthens winds on average, pushing surface water outward and turning the deep, warm ocean layer inward. "It used to happen before climate warming kicked off," Scambos said, "but now happens more often. It's changing the continent's stability." Not every glacier is as unstable as the Thwaites Glacier, but even on its own, Thwaites is a major factor in future change scenarios. If Thwaites melted, it would change the dynamics of the entire region. "When the Thwaites Glacier changes, it won't happen in isolation," Scambos said. Though the entire ice sheet may not immediately run away, the impact would disperse, and if the entire WAIS followed a similar demise, sea levels would rise 3 to 4 meters (10 to 13 feet).

## Humpty dumpty

Melting is expected to increase as climate change progresses. Still, it will take centuries for the gigantic Thwaites ice mass to melt away. However, a new factor threatens faster deterioration. Rather than a gradual lift off, grounding lines could thin and split off the ice shelf, forming an ice cliff. If the ice cliff reaches 90 meters (295 feet), it will topple. "This is something so simple I can't believe we missed it for so long," Scambos said. "Ice is just not strong enough to support a cliff more than 300 feet tall."

It has happened before. In 2008, Jakobshavn, Greenland—the largest glacier on Earth's second largest ice sheet—an ice cliff formed when glaciers retreated. Since then, the ice cliff repeatedly peels off. So this huge glacier has retreated twelve miles in fifteen years. As soon as a new cliff is exposed, cracks form on top and the glacier almost continuously calves away, crumbling quickly. If this scenario unfolds on the Antarctic Ice Sheet, it would mean Thwaites Glacier could deteriorate much sooner, possibly in as little as 50 to 100 years. "It's not clear how this would happen," Scambos said. "We haven't seen basal melting to the point where an ice shelf just falls apart. We haven't seen this play out in West Antarctica yet." Thwaites is only one element of suspense surrounding ice decline in the WAIS, where mass loss increased by 75 percent from 1996 to 2006. In 2014, with warming waters and stronger winds around Antarctica, several studies concluded the inevitable decline of West Antarctic glaciers. Scambos recently published a briefing discussing Antarctic mass loss and future sea level rise, including the potential demise of Thwaites. He said, "Our summary paper advertises and underscores the results from several papers." ›




*This color map shows bedrock elevation beneath the central West Antarctic Ice Sheet. Blue is well below sea level (about 1500 meters below present-day sea level). Red is higher bedrock level. Sea level is orange-red. Note that the entire area in this map is covered in thick ice, except for the two white patches where some mountains are exposed.*

*Credit: Joughin et al.*

## Evaluating Arctic sea ice predictions

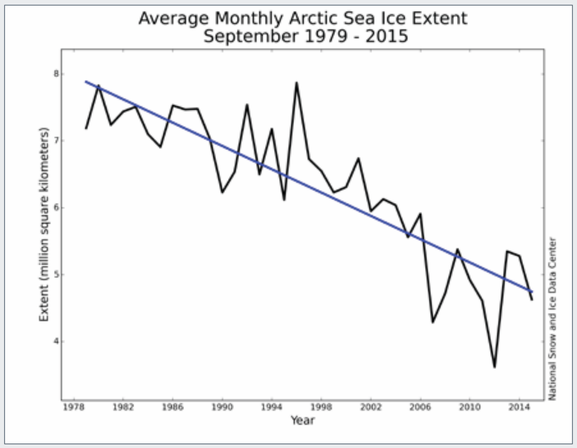
*U.S. Coast Guard Cutter Healy cuts through thick multiyear ice in the Arctic Ocean to get researchers to remote research sites. The ICESCAPE mission, or "Impacts of Climate on Ecosystems and Chemistry of the Arctic Pacific Environment," was a NASA shipborne investigation that took place in the Beaufort and Chukchi seas in summer 2010 and 2011.*

*Credit: Kathryn Hansen, NASA*

Scientists expect Arctic summer sea ice to eventually disappear. Conservative estimates put the timeline by the end of the century, while more aggressive estimates suggest the Arctic Ocean may be free of summer sea ice within two or three decades. Such a change requires people living and working in the Arctic to prepare. With less sea ice, will oil and gas exploration and extraction increase? Will Arctic tourism rise, and if so, how will it effect surrounding environments, wildlife, and inhabitants? Will some communities face relocation? And how can field researchers continue to safely study the ice? Those questions cannot be answered without knowing where and when ice may occur. But predictions are a bit tricky, especially for atypical years. NSIDC research scientist Julienne Stroeve wanted to know the quality of current predictions; so she compared forecasts to actual observations. "Just how well are we doing?" Stroeve asked.

### The life cycle of sea ice

Yearly, sea ice ebbs and flows, reaching its maximum in March and minimum in September. Sea ice extent since the early 1970s, when satellite monitoring began, is in a downward trend. Its minimum extent declines at an average linear rate of 13.4% per decade. In September 2012, sea ice extent set a new record—dropping an area about the size of Texas from the pervious record set in 2007. The new record extent lost 2.83 million square kilometers (1.09 million square miles) below the 1981 to 2010 average minimum, representing an area nearly four times the size of Texas.




*Monthly September ice extent for 1979 to 2015 shows a decline of 13.4% per decade relative to the 1981 to 2010 average.*

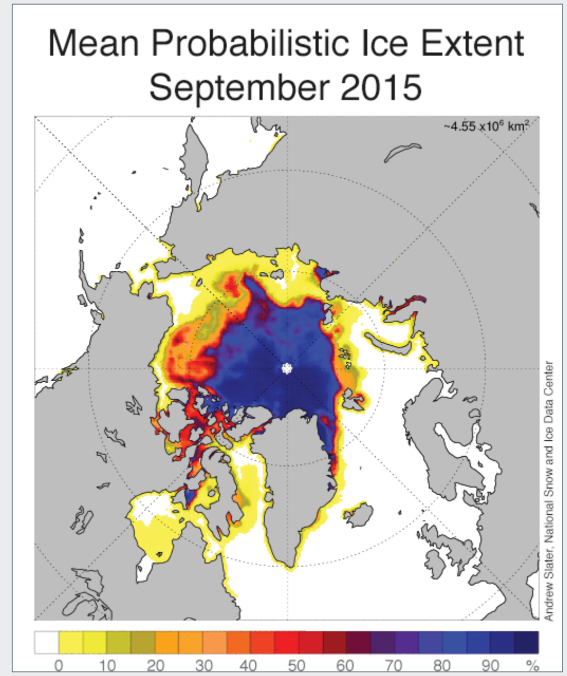
*Credit: NSIDC*

Another way to consider the decline: the nine lowest September ice extents over the satellite record have all occurred in the last nine years. Though not every year is a record-breaking low, the trend is undeniable. For those keeping an eye on sea ice, predicting the quality of ice (thickness) and its location (where and when) is tantamount to the success of Arctic operations. Predictions have moved forward a bit. "Beforehand, it was just sea ice extent," Stroeve said, "but now we're also getting spatial maps of ice probability." Total extent is just a number, the total area, but it is not practical for people working in the Arctic. The spatial maps offer the location of ice. Though this adds valuable information for seasonal predictions of sea ice, how accurate is the information?

## On modeling

In 2008, the Study of Environmental Change (SEARCH) program solicited input from the research community, which used a wide variety of methods to garner estimates on predicting sea ice extent every year. In 2013, a newly funded interagency project, the Sea Ice Prediction Network (SIPN), took over SEARCH's synthesis effort. "This brings together a bunch of researchers from different institutes to create a network of scientists and stakeholders trying to advance sea ice forecasting on the seasonal timescale," Stroeve said.

Current forecasts do not do so well. Andrew Slater, a NSIDC research scientist, developed a statistical forecast to calculate the probability of ice for a given location (i.e., at each grid cell). "Right now his forecasts as a whole do better than the dynamical forecasts," Stroeve said. A dynamical model simulates the interaction of important components to climate, such as ocean, atmosphere, land surface, and ice. It estimates the energy balance, where solar energy enters, and heat disperses into various outlets like the oceans and atmosphere. Slater's statistical forecast, on the other hand, is not interested in all the details of the sea ice environment. Instead, he takes a low sea ice situation and continues the anomaly




*The above graph shows a forecast of mean probabilistic Arctic sea ice extent for September 2015 (issued August 9, 2015). The forecast value, or expected September mean Arctic sea ice extent, is 4.55+/-0.35 million square kilometers.*

*Credit: Andrew Slater, NSIDC*

linearly. Models can run a forecast at any point, but seasonal forecasts improve the closer they get to the date of prediction. Slater's model fares best for a 50-day lead, but is not good the further out it begins. Slater's model predicted record-breaking lows for 2005, 2007, and 2012.

## The future of predictability

Communities that need to resupply in the fall need to know the time and place of freeze-ups.

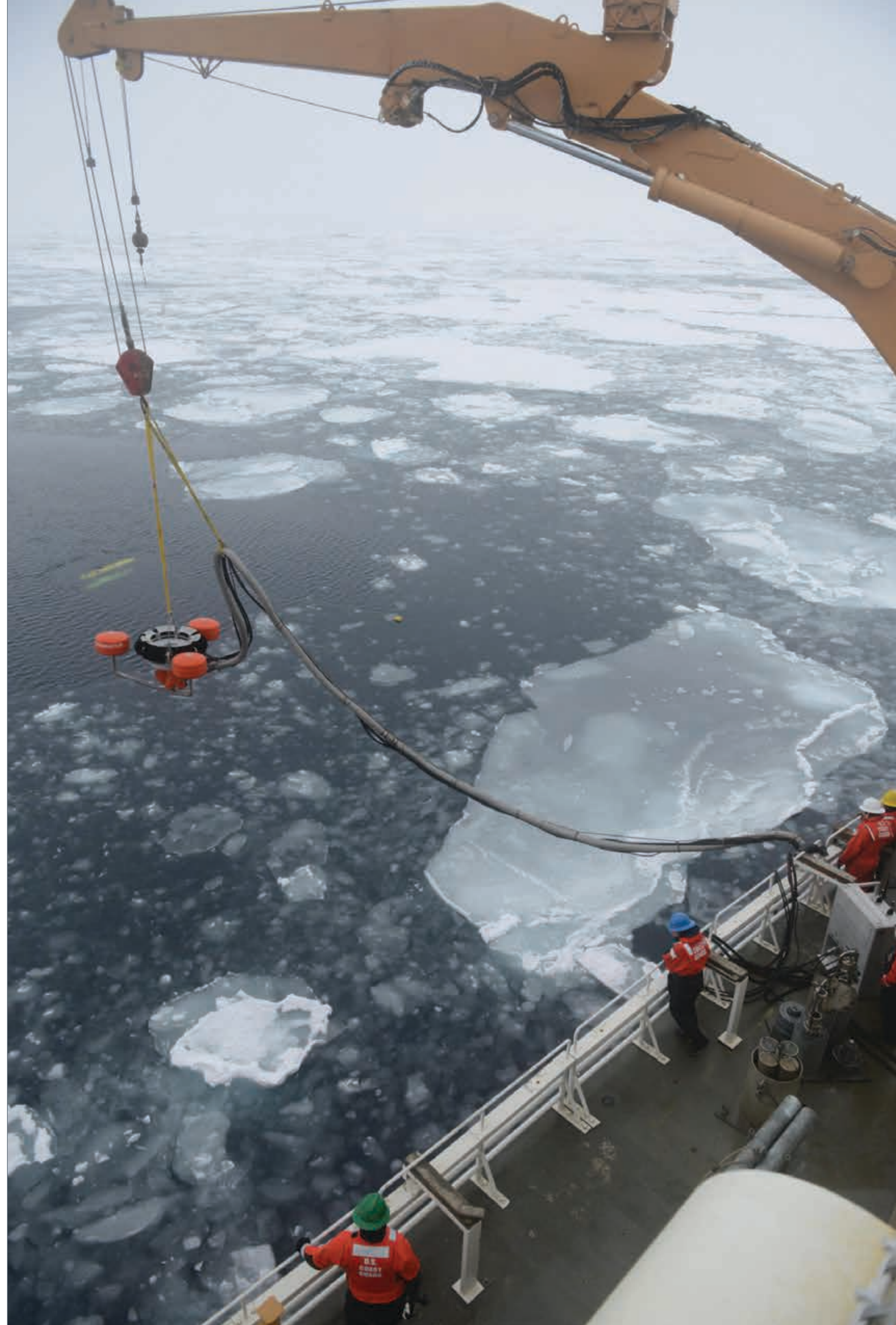
*On the eastern side of Northern Greenland, hunters travel out to sea in search of seals.*

*Credit: Visit Greenland-Mads Pihl/flickr*

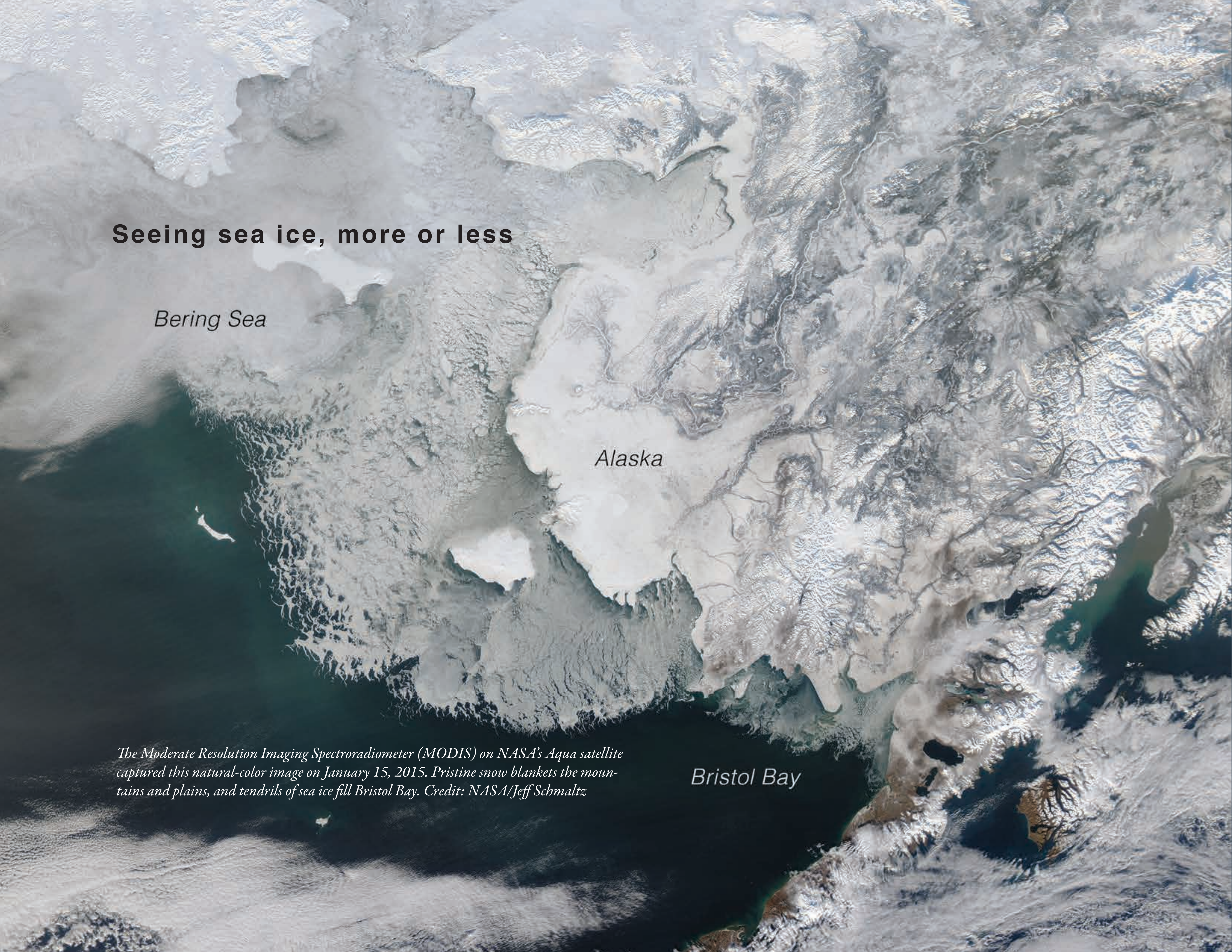
“We need to communicate to different stakeholders what the prediction skill is and how much to trust results,” Stroeve said. A false green light may trap ice-breakers, halting supplies.

Stroeve hopes to put some of these models head-to-head. These intercomparison projects measure the sensitivity of models. So if everyone uses the same input data, it helps scientists see which models perform better. It is a way to tweak the machine to get the ultimate model. “So should we put more effort to make sure we have all the observations we need to drive the models or do we need to put more effort in improving the models themselves? What would bring the most improvement?” Stroeve asked.

Stroeve, however, is not that optimistic about the future of forecasting. A key component of sea ice predictions requires a better sense of summer weather patterns. “Weather forecasts are not good for more than week or two out. We’re just not there. It’s too complex. It’s too chaotic,” Stroeve said. Without knowing what the weather will do, predictability will continue to be limited. Sea ice extent is shrinking, but also there is less multi-year ice, ice that has been around for two or more years. As the ice thins, climate models exhibit more year-to-year variability. “So our skill may actually decrease in the future,” Stroeve said. “That’s one of the things we need to better understand thinning ice. For now, we don’t know.” However, fostering dialogue between scientists, their models, community observers, and stakeholders requires a forum. SIPN now hosts bimonthly webinars. The informal exchange of information may better forecasting as new frontiers open in the Arctic. In 2014, Geophysical Research Letters published Stroeve’s findings. Read it here. Earth & Space Science News also published her research in 2015.



# Seeing sea ice, more or less

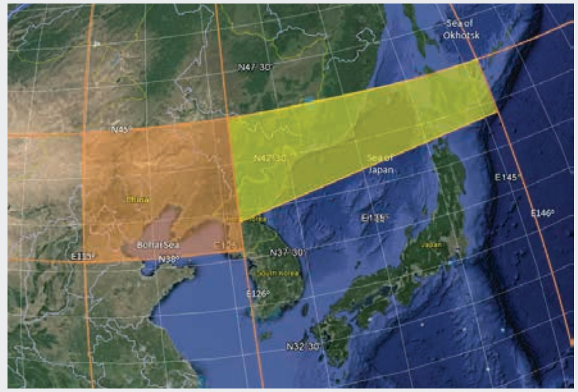



*The Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite captured this natural-color image on January 15, 2015. Pristine snow blankets the mountains and plains, and tendrils of sea ice fill Bristol Bay. Credit: NASA/Jeff Schmaltz*

Observing sea ice from space is sometimes tricky. Water vapor in the atmosphere makes seawater look like ice. Coastlines covered with ice make nearby ocean look iced-over, a problem called land-ocean spillover. Scientists adjust for such misinterpretations by creating masks based on previous sea ice conditions to conceal problem areas and highlight areas they know contain valid ice. The masks need to be adjusted for other factors, too, such as shifting sea ice patterns or varying orbit angles between different satellites. At NSIDC, scientists recently discovered their sea ice masks for passive microwave satellites could use a fresh update.

## Ice adjustment

Sea ice in the Bering Sea is more extensive in recent years, but since the old masks were created using maximum ice extent data collected before this trend, they were missing valid ice. NSIDC scientist Julienne Stroeve said, “We noticed we were cutting off ice in the Bering Sea. We were expecting more sea ice in that area from winter through May.” In other areas of the Arctic, the masks were adding erroneous ice. Correcting those errors was time consuming. It meant scrutinizing individual pixels to adjust the masks and re-apply them. Regular tweaks made record keeping complicated, and that made sharing the masks with other researchers more difficult. But now, NSIDC has created new masks that are both more accurate and readily available. NSIDC data manager Donna Scott said, “These new masks give us even more confidence in the data and they have better provenance. We know exactly how they were created and they’re well documented, so there’s much more transparency for the user.”




*This map shows the expanded coverage of the Polar Stereographic Valid Ice Masks Derived from National Ice Center Monthly Sea Ice Climatologies. Areas where sea ice may sometimes be present include portions of the Bohai Sea (orange) and the Seas of Japan and Okhotsk (yellow).*

*Credit: NSIDC/Google Earth*

The new masks also set more realistic boundaries for where sea ice has historically been present. Previous masks had been based only on satellite data, but the new masks are based on National Ice Center (NIC) Arctic Sea Ice Charts and Climatologies. NIC charts and climatologies draw from multiple sources, such as ships and buoys, as well as satellites. Records for those sources extend as far back as 1972, six years before the satellite-based sea ice record began. And NIC sea ice analysts create each chart by painstakingly interpreting the ice in each pixel. Yet there was still room for improvement, the team found. Stroeve said, “NIC didn’t extend as far south [in the Northern Hemisphere] as we needed, so we expanded the masks.” The new masks, called the Polar Stereographic Valid Ice Masks Derived from National Ice Center Monthly Sea Ice Climatologies, bring previously unaccounted portions of sea ice into view in the Bohai Sea, the Sea of Japan, and the Sea of Okhotsk.

## Closing gaps

The new masks have streamlined the suite of NSIDC passive microwave sea ice data sets. Before, NSIDC used separate masks for each data set. Scott said, “The process is much more systematic now because we have one set of masks that we can apply to several data sets.” Scott’s team also updated the sea ice suite to close a gap near the North Pole. Satellites in polar orbits, like those in the Defense Meteorological Satellite Program (DMSP), are tilted slightly away from the poles, so they do not pass directly over them. This means there is a small area called a pole hole that the instruments cannot view. However, the newest DMSP instrument, the Special Sensor Microwave Imager/Sounder (SSMIS), is tilted closer to the pole than its predecessors, the Scanning Multichannel Microwave Radiometer (SMMR) and the Special Sensor Microwave Imager (SSM/I). SSMIS can therefore observe more sea ice. As a result, data sets like the popular Sea Ice Index, which tracks Arctic- and Antarctic-wide changes in sea ice, now include approximately 300,000 square kilometers of additional coverage for the Northern Hemisphere. And like the new sea ice masks, these updates come with detailed records that provide a clear history for data users. Stroeve said, “We’re improving the data and we’re also being transparent about what we’re doing with the data.”

## A sharper view of the ice edge

In the waters north of Alaska, ships can go for weeks without seeing another vessel. Fog frequently blankets the region in the spring and summer when the sea ice melts and recedes towards the North Pole. This season of melt has attracted more oil-seeking rigs and vessels over the last five years, taxing the U.S. Coast Guard ships that patrol these waters.

For ships in the Arctic, the ice edge is everything. The mutable edge dictates how much fuel and supplies need to be on the vessel. The closer the edge is to the pole and the farther out ships get, the more dangerous the voyage becomes. Researchers at NSIDC and their colleagues have developed a way to improve sea ice edge forecasts in the Arctic. The new method bumps up the accuracy of the six-hour forecast by almost 40 percent, making forecasts more reliable and navigation in the Arctic safer.

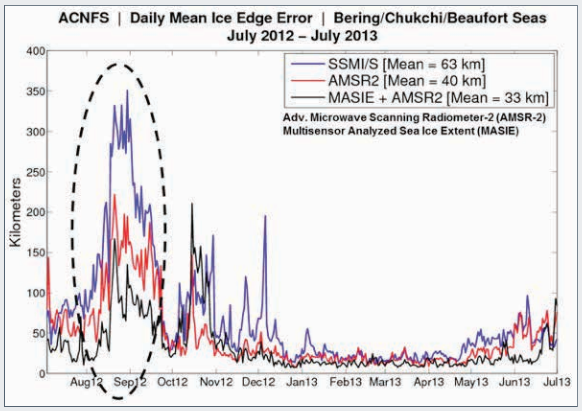
Sea ice measuring one to twelve feet thick covers much of the ocean throughout the year. Its extent waxes and wanes with the seasons. Although frequent harsh weather and sea conditions keep most commercial ships out of the region, some ships are able to navigate near the ice edge where large chunks of sea ice are less likely to gouge their vessels. Since satellites started measuring Arctic sea ice extent in 1979, summer extent has trended downward with a record minimum of 3.39 million square kilometers occurring in September 2012. Scientists foresee that this rapidly changing Arctic environment could spur an increase in Arctic ship traffic over the next decade. This, in turn, demands an increase in U.S. military presence in the Arctic and better sea ice edge forecasts.

### High-resolution ice

The Navy currently uses two methods, the Arctic Cap Nowcast/Forecast System (ACNFS) and the Global Ocean Forecast System, to predict ice conditions. The forecasts alert navigators six hours out with a spatial resolution of about 25 kilometers. However, researchers at NSIDC, NASA, and the NOAA National Ice Center (NIC) realized that an ice concentration data product from the Advanced Microwave Scanning Radiometer (AMSR2) on Japan's GCOM-W1 satellite could be used to improve

*The Los Angeles-class attack submarine USS Hampton breaks thin ice to surface in the Arctic Ocean during the 2014 ICEX campaign.*

*Credit: US Navy courtesy Hamilton Ingalls Industries, Chris Oxley*




*This graph shows the daily mean error in kilometers for the Bering/Chukchi/Beaufort seas versus time for ACNFS ice edge against the independent ice edge analysis from the NIC over the validation period 1 July 2012 to 1 July 2013. The blue line shows the use of SSMIS assimilation only, the red line shows the use of AMSR2 assimilation only and the black line shows the use of the blended AMSR2 + MASIE assimilation. The blended product shows the greatest reduction in daily mean error. Credit: Posey et al, 2015.*

the ice models that the forecasts are run on. The product has a resolution of ten kilometers.

"Our idea was pretty simple, to combine two types of measurements," said Florence Fetterer, an NSIDC researcher. With colleagues from NASA, NIC, and the U.S. Naval Research Laboratory (NRL), Fetterer blended data from AMSR2 with a sea ice mask called MASIE ("may-zee," the Multisensor Analyzed Sea Ice Extent), developed at NSIDC. The MASIE sea ice mask catches ice that the microwave data alone miss, especially in summer, when melt ponds on the surface of the ice appear as ocean to the sensor. Where there is ice, the AMSR2 product supplies an estimate of ice concentration that the forecast model needs. The resulting high-resolution dataset can capture even small patches of sea ice a few miles across. That means better input into forecasts, and more accurate output, too.

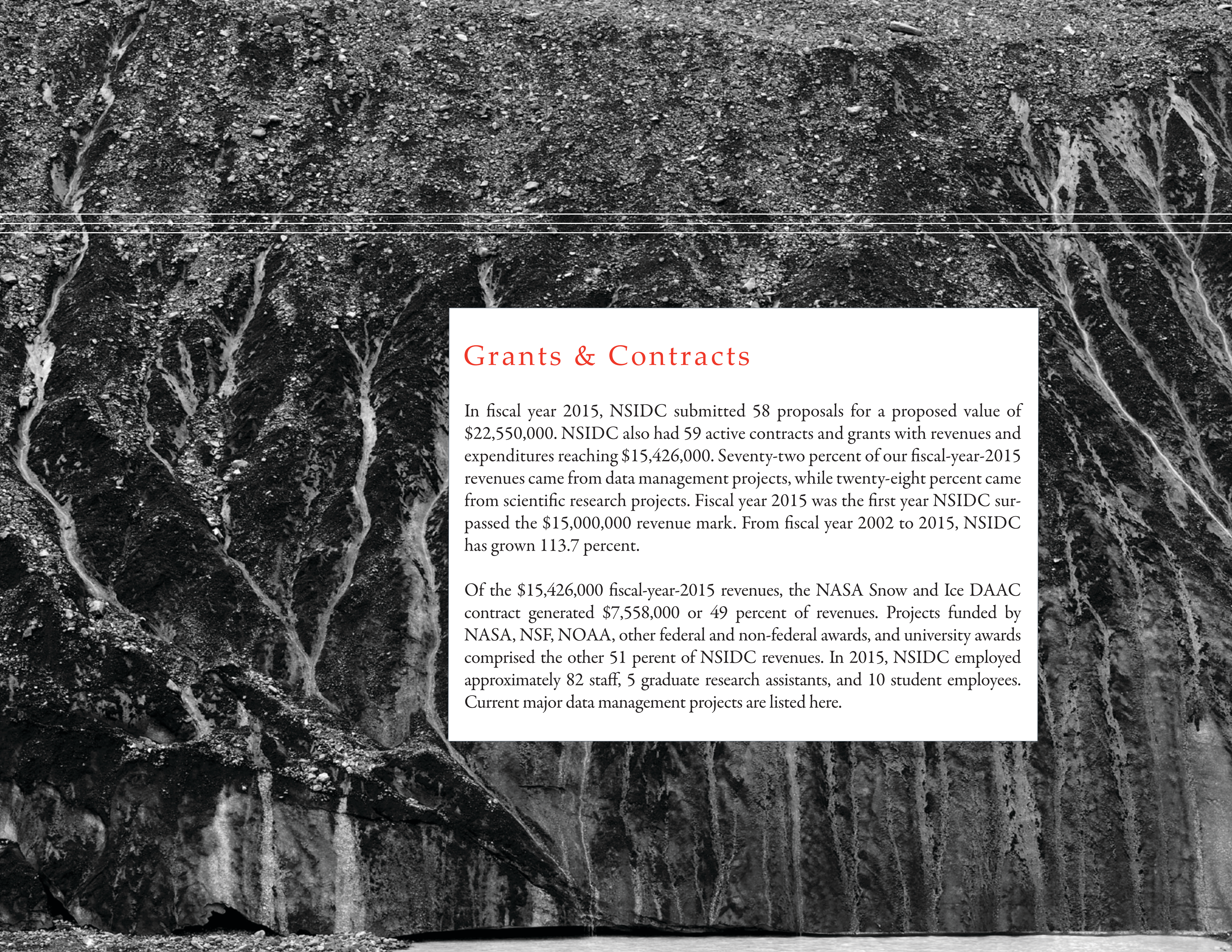
"We expect this combined product is going to do a much better job at initializing the Navy's forecast model," Fetterer said.

## Forecast vs. observation

The Navy used the new technique this summer as part of its support to the U.S. Coast Guard icebreaker Healy, which conducted missions in the Beaufort Sea with a transit to the North Pole to study the biogeochemistry of Arctic waters. The Navy has used the blended product to provide sea ice edge forecasts at a sharper 2-kilometer resolution since July 2015. The researchers compared the new forecasts to actual observations of the sea ice edge and found a 40 percent improvement in accuracy all year round.

"It is really helping us, and it's providing a better product for the whole community that uses and depends on accurate sea ice information, from forecast modelers to anybody with assets in the Arctic," said Pablo Clemente-Colón, chief scientist of the NIC, a collaboration of the Navy, NOAA and the U.S. Coast Guard.

"It's especially important to have accurate forecasts given rapidly changing conditions in the Arctic," said Pamela Posey, a researcher at the NRL in Mississippi. The scientists detailed the new method in a study published in August 2015 by the journal The Cryosphere. The blended dataset is updated daily and is available from the NSIDC web site.



## Grants & Contracts

In fiscal year 2015, NSIDC submitted 58 proposals for a proposed value of $22,550,000. NSIDC also had 59 active contracts and grants with revenues and expenditures reaching $15,426,000. Seventy-two percent of our fiscal-year-2015 revenues came from data management projects, while twenty-eight percent came from scientific research projects. Fiscal year 2015 was the first year NSIDC surpassed the $15,000,000 revenue mark. From fiscal year 2002 to 2015, NSIDC has grown 113.7 percent.

Of the $15,426,000 fiscal-year-2015 revenues, the NASA Snow and Ice DAAC contract generated $7,558,000 or 49 percent of revenues. Projects funded by NASA, NSF, NOAA, other federal and non-federal awards, and university awards comprised the other 51 perent of NSIDC revenues. In 2015, NSIDC employed approximately 82 staff, 5 graduate research assistants, and 10 student employees. Current major data management projects are listed here.

# NSIDC Major Grants & Contracts

## Distributed Active Archive Center (NASA)

The NSIDC DAAC is one of NASA's Earth Observing System Data and Information System (EOSDIS) data centers. The NASA data centers process, archive, document, and distribute data from NASA's past and current Earth Observing System (EOS) satellites and field measurement programs. Each data center serves one or more specific Earth science disciplines and provides its user community with data products, data information, user services, and tools unique to its particular science. Each data center is also guided by a User Working Group in identifying and generating these needed data products. The NASA data centers serve as the operational data management and user services arm of EOSDIS, performing such tasks as data ingest and storage, filling user orders, answering inquiries, monitoring user comments, and providing referrals to other data centers. (http://nsidc.org/daac/index.html)

## Advanced Cooperative Arctic Data and Information Service (ACADIS, PI M. Serreze and J. Moore, UCAR)

ACADIS is designed to manage the diverse data needs of the Arctic research community supported by the NSF Office of Polar Programs (OPP) Division of Arctic Sciences (ARC). ACADIS is a collaborative effort between the National Snow and Ice Data Center (NSIDC), the University Corporation for Atmospheric Research (UCAR), and the National Center for Atmospheric Research (NCAR). It represents an expansion of the Cooperative Arctic Data and Information System (CADIS) system originally developed by NCAR, NSIDC and UCAR, which provided data management support and archival services for the Arctic Observing Network (AON) for nearly four years. ACADIS, by contrast, is serving needs of the broader Arctic NSF-funded community, including, but not limited, to projects funded by OPP under AON, Arctic System Sciences (ARCSS), Arctic Natural Sciences (ANS) and the Arctic Social Sciences Program (ASSP).

ACADIS is designed to allow scientists an easier path to archive, access, integrate and work with data spanning multiple disciplines. ACADIS is providing data ingest and access services to scientists, decision-makers and other Arctic stakeholders, as well as archival services to ensure data accessibility through the coming years and decades.

*Opposite: This textured wall, grooved by waterfalls, is the toe of Athabasca Glacier in the Canadian Rockies. Credit: A. Pope, NSIDC*

NSIDC is focused on improving the discoverability, accessibility, and usability of NSF data in conjunction with broader Arctic data holdings from other agencies and countries. NSIDC also works with UCAR/NCAR on data stewardship, integration and (as is necessary), customized services, and activities for a broad user community. For each potential value-added product or activity, NSIDC scopes the level of effort required and meets the need based on recommendations by the ACADIS Data Advisory Committee (ADAC) and NSF management.

## Antarctic Glaciological Data Center (NSF)

The AGDC archives and distributes Antarctic glaciological and cryospheric system data collected by the U.S. Antarctic Program. It contains data sets collected by individual investigators and products assembled from many different PI data sets, published literature, and other sources. The catalog provides useful compilations of important geophysical parameters, such as accumulation rate or ice velocity (http://nsidc.org/agdc).

## Collaborative Research: ELOKA Phase III

Toward Sustainable Data Management Support for Community Based Observation Contributing to the Arctic Observing Network (NSF): ELOKA facilitates the collection, preservation, exchange, and use of local observations and knowledge of the Arctic. ELOKA provides data management and user support, and fosters collaboration between resident Arctic experts and visiting researchers. By working together, Arctic residents and researchers can make significant contributions to understanding the Arctic and recent changes (http://eloka-arctic.org).

## Operation IceBridge (NASA)

NASA's Operation IceBridge, initiated in 2009, collects airborne remote sensing measurements to bridge the gap between NASA's Ice, Cloud and Land Elevation Satellite (ICESat) mission and the upcoming ICESat-2 mission. IceBridge mission observations and measurements include coastal Greenland, coastal Antarctica, the Antarctic Peninsula, interior Antarctica, the southeast Alaskan glaciers, and Antarctic and Arctic sea ice. The IceBridge mission combines multiple instruments to map ice surface topography, bedrock topography beneath the ice sheets, grounding line position, ice and snow thickness, and sea ice distribution and freeboard. Data from laser altimeters and radar sounders are paired with gravitometer, magnetometer, mapping camera, and other data to provide dynamic, high-value, repeat measurements of rapidly-changing portions of land and sea ice (http://nsidc.org/data/icebridge/index.html).

## NOAA@NSIDC

The National Oceanic and Atmospheric Administration team at NSIDC manages, archives, and publishes data sets with an emphasis on in situ data, data sets from operational communities such as the U.S. Navy, and digitizing old and sometimes forgotten but valuable analog data. We also help develop educational pages, contribute to larger center-wide projects, and support the Roger G. Barry Archives and Resource Center (ARC) at NSIDC (http://nsidc.org/noaa).

*An iceberg floats in the Beascochea Bay, Antarctica.*

*Credit: T. Scambos, NSIDC*

# 2015 Publications

## Journal Articles

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**NSIDC researchers and scientists are listed in bold.**

*Opposite: A humpback whale feeds on krill near the Antarctic Peninsula. Credit: Glenn E. Grant, NSIDC*

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