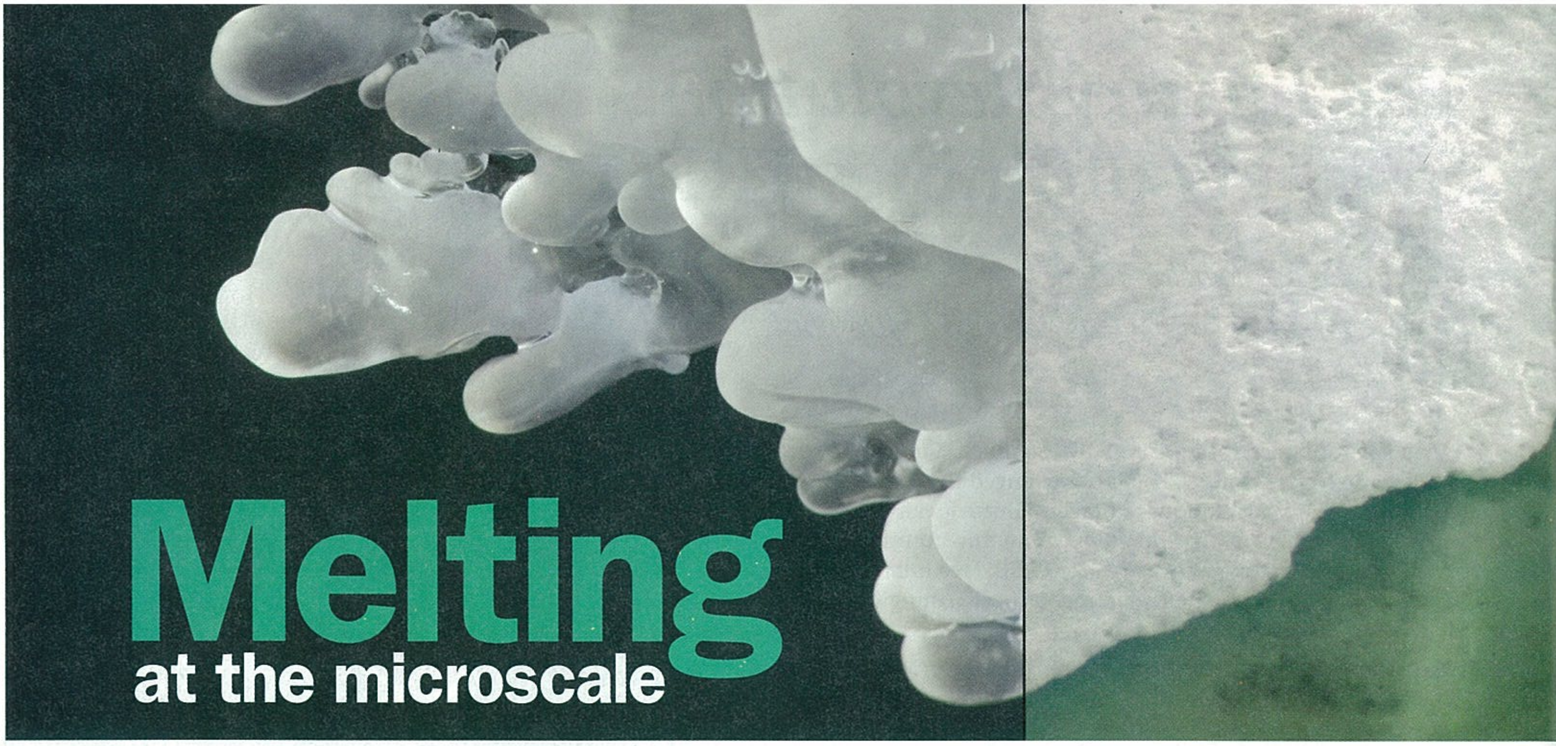


Melting at the microscale

Studying sea ice close-up may improve climate models By Alexandra Witze

Earth's northern polar cap is disappearing at unprecedented rates. To understand why, researchers are getting up close and personal with ice.

Using satellites, scientists get a broad perspective on how the skin of sea ice atop the Arctic Ocean shrinks, on average, just a little bit more every summer. But zooming down to within a few meters of the surface brings some important little things into view. In particular, "microphysical" properties of the ice, such as how salty water percolates through it, turn out to play a surprising role in ice behavior.

Yet most models of melting don't incorporate information about sea ice microphysics. So some researchers are pushing to learn more about the ice's physical properties and to include the findings in next-generation analyses. "It's clear that we need to do better in terms of understanding and predicting the fate of the polar ice cap," says Kenneth Golden, a mathematician at the University of Utah in Salt Lake City who studies sea ice. "Monitoring transport processes in the sea ice is critical for understanding climate change."

New studies of ice microphysics at both poles may help. Already, measurements taken from an icebreaker in Antarctica are illuminating how the flow of salt water — called brine — affects the electrical conductivity of sea ice. Computer models are exploring how algae and other living creatures influence its physical properties. And studies off the coast of Alaska are quantifying how meltwater can pool atop the ice or drain through it, changing how much heat from the sun the ice reflects or absorbs.

Studying sea ice microphysics is challenging, in part because of the sheer complexity of the material. Unlike the freshwater ice found in glaciers or lakes, sea ice is a complicated mix of pure ice, brine, air and solid salts. How those materials are distributed within the ice changes constantly as temperature, salinity and other factors rise and fall.

"We haven't tackled these complexities in modeling the ice cover, but I think we're at a place where we can make a lot of progress," says Marika Holland, a climate modeler at the National Center for Atmospheric Research in Boulder, Colo.

The work could eventually have practical implications for those who monitor changing sea ice conditions, such as native communities relying on ice for hunting walrus or shipping companies wanting to know when they can send freight through an ice-free Northwest Passage.

The alarming rate at which the Arctic ice cap is shrinking is triggering much of the new research. Since 1979, the amount of ice covering the Arctic Ocean in September, at the end of the melt season, has dropped more than 11 percent per decade. In 2007 Arctic ice reached its smallest minimum ever observed, at about 4.2 million square kilometers — a level scientists call "shocking" *(SN: 10/13/07, p. 238)*. The two summers since then have both seen a larger September ice cap, but the long-term trend of decline is unmistakable, Holland says.

In the Southern Hemisphere, the sea ice pack that rings Antarctica has not shown a similar decline, perhaps because of the anchoring land mass at the center. Still, the basic principles governing sea ice physics are the same in both north and south.

Inner-ice flows

Golden's studies aboard Antarctic icebreakers have led to new insights into ice microstructure *(SN: 8/12/00, p. 106)*. In the mid-1990s, he reported finding an "on/off" switch that controls permeability in sea ice — that is, how the salty water

BOTH IMAGES: STEVEN KAZLOWSKI/SCIENCE FACTION/CORBIS

lying under and around a floating piece of ice can begin to circulate into it.

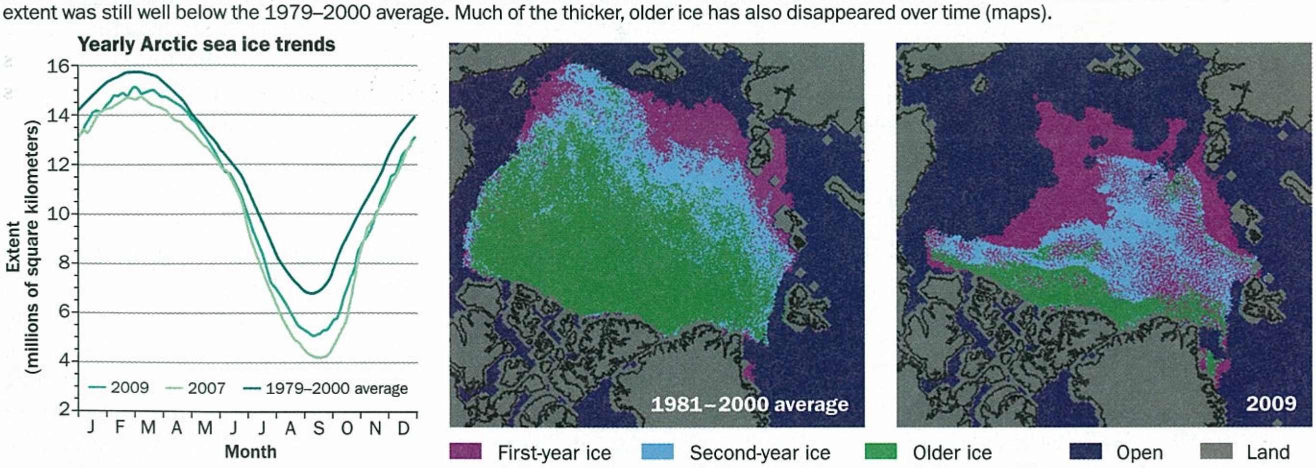
Assuming the fraction of sea ice made up of brine is about 5 percent, below temperatures of about −5° Celsius, the brine cannot percolate up through the ice. Above that critical temperature, though, the fluid begins to flow, an observation Golden dubbed the "rule of fives." The warmer it gets, the more permeable the ice becomes. Fluid flow picks up, with pockets of brine connecting and forming channels. Because salt lowers the melting point of ice, the amount of brine influences when ice starts melting in the summer and freezing again in the winter.

More recently, Golden and colleagues have studied pack ice off the coast of East Antarctica. Salt water contains ions, or charged particles, of elements such as sodium and chlorine, and the presence of those ions means that electricity conducts more readily through salt water than through freshwater. Golden's team has used electrical conductivity as a sort of proxy for studying brine's flow. In a paper now under review, the scientists report working out the mathematics of the electrical conductivity of sea ice off Antarctica. Further calculations building on the field observations, the team writes, "lay the groundwork for relating the fluid and electrical properties of sea ice."

Climate models predict declines in Arctic sea ice (above), but rarely do such calculations consider what happens at the ice-water interface (far left).

Observations in the Arctic support this relationship between fluid and electrical properties. Hajo Eicken, a sea ice specialist at the University of Alaska Fairbanks, has been working for years in the young "landfast" ice that abuts the shore off Barrow, Alaska. He and his colleagues have shown how ice microstructure changes over the course of

A history of loss On average, the Arctic ice cap has been shrinking since satellite observations began three decades ago. Overall ice extent at the end of the melt season, in September, has shrunk, bottoming out in an all-time low in 2007 (graph). Though 2009 saw an increase over 2007, the ice extent was still well below the 1979–2000 average. Much of the thicker, older ice has also disappeared over time (maps).



SOURCE: NATIONAL SNOW AND ICE DATA CENTER

First-year ice (<1 year old) Second-year ice (1–2 years old) Older ice (>2 years old) Open water Land

NSIDC, COURTESY OF C. FOWLER AND J. MASLANIK/UNIV. OF COLORADO a season, such as during the spring warming. At the start of the season, when temperatures are still quite cold, electricity appears to flow upward from the ice-water interface. But electricity doesn't start to flow laterally until temperatures warm up and, presumably, permit brine pockets to connect horizontally as well as vertically.

Sloshing and pooling

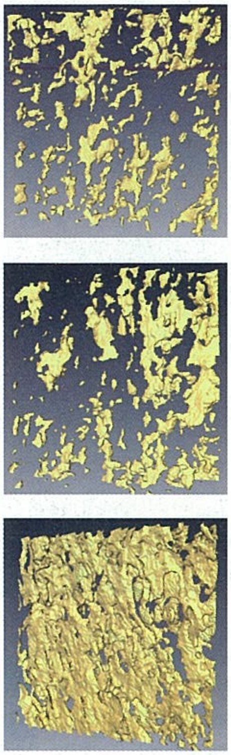
Such discoveries can help explain the behavior of another key player in the sea ice regime: life. Fluid within sea ice sustains a large community of organisms, including algae, bacteria and worms.

Ice algae in particular are a major component of the Arctic's marine food web. They endure harsh winters in the nooks and crannies of sea ice, and when temperatures rise in spring, the life expands rapidly throughout the ice's lower layers. When the ice melts completely, it releases algae into the ocean, where plankton and other creatures feed on the photosynthetic organisms in a massive bloom of biological activity.

The presence of algae alters sea ice in a number of ways, such as producing chemicals that can depress the freezing temperature of ice, or darkening the ice so that it absorbs more sunlight. Yet the interplay has hardly been studied, in part because biologists and physicists rarely mix. "All our global climate models are missing this physics," says Cecilia Bitz, a modeler at the University of Washington in Seattle.

Bitz is trying to change that, and in preliminary work she has modeled in one dimension how fluid flow affects algae within sea ice. Much work remains to be done, and one of the biggest challenges is modeling convective flow within the ice structure, she reported in February in San Diego at a meeting of the American Association for the Advancement of Science. Still, such studies could eventually illuminate how life affects the microphysics of sea ice all year, including during the melt season.

Melting ice also plays another important role in the ecosystem — changing the albedo, or reflectiveness, of the ice surface. This "ice albedo effect" is



Salty meet up Computer renderings of a lab-grown sea ice crystal show how brine pockets (gold) connect to form channels as temperatures increase from −15° Celsius (top) to −6° C (middle) to −3° C (bottom). The amount of brine flowing through the ice can affect melting and freezing rates.

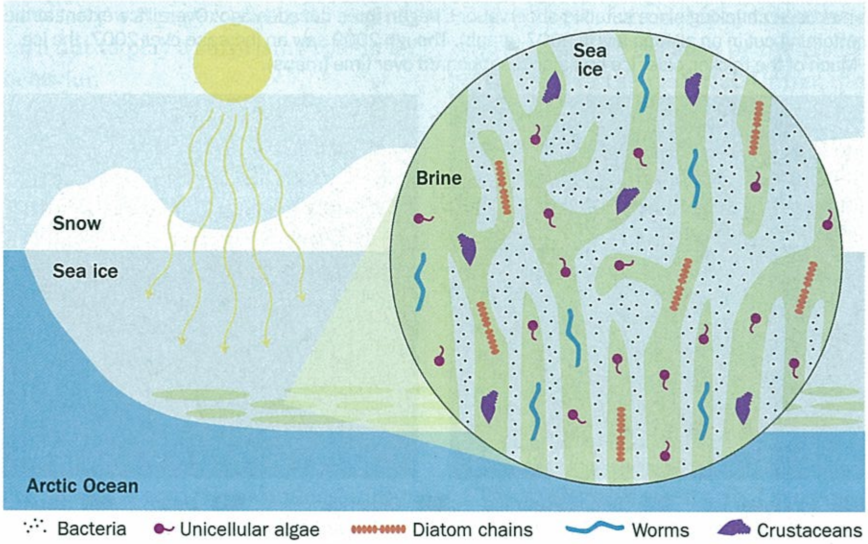
one of the great unknowns in climate physics, as researchers struggle to understand what causes the ice surface to change its reflectivity (*SN: 11/12/05, p. 312*). Pure ice, like a white rooftop, reflects nearly all sunlight back into space. Open water, like an expanse of asphalt, absorbs much more radiation and hence heats up quickly. Melt ponds atop the sea ice are somewhere in between — darker than ice but lighter than water.

"There's not a simple binary system of snow-covered ice and open water," Donald Perovich, a sea ice specialist at the U.S. Army Cold Regions Research and Engineering Laboratory in Hanover, N.H., said at the AAAS meeting. "There's a mosaic of ice and melt ponds and open ocean."

How melt ponds form and spread is, of course, controlled by the microphysics of the sea ice — in particular its permeability, or how readily fluid can move within it. Once the summer melt season starts, ponds can appear and disappear within a matter of days, changing rapidly in size. Each one alters the albedo of the ice cap, and even small changes in albedo can have a big impact on how ice survives the melt season.

As part of the studies off Barrow, Eicken and colleagues have been monitoring how melt ponds and their albedos evolve over time. Much, it turns out, depends on the type and age of ice involved. For instance, on first-year ice — frozen over just one winter — meltwater pools to about 2 or 3 centimeters thick, says Eicken. But on multiyear ice — which has piled up

Life at the boundary An array of critters, not just the iconic polar bear, make their homes in and on the sea ice. Crustaceans, worms, bacteria and algae reside within the brine channels that form in the sea ice, as depicted below. During the spring and summer especially, algae concentrate in the ice's lower layers, pooling organic material there. These organisms are known to sculpt their habitats, and though much research still needs to be done, scientists suspect that such residents may have an important effect on yearly changes in sea ice extent.



FROM TOP: K.M. GOLDEN *ET AL./GEOPHYSICAL RESEARCH LETTERS* 2007; T. DUBÉ, ADAPTED FROM WWW.ARCTIC.NOAA.GOV/ESSAY_KREMBSDEMING.HTML year after year without melting away in the summer — meltwater ponds are only about 1 centimeter deep, meaning they are lighter than the ponds on younger ice. "Is there something we're missing about the permeability structure that allows water to pool in first-year ice?" asks Eicken.

For now, the answer seems to be maybe. One way to make progress on such questions may be to once again pull back on perspective, leaving the world of ice microphysics and zooming out to a full view of the ice cap.

Here, too, researchers have much to do. In particular, scientists lament the lack of regular measurements of ice thickness across the Arctic ice cap. Such observations can help distinguish between thinner first-year ice and thicker multiyear ice, which behave very differently from each other. But there are few options for obtaining this data reliably.

NASA's ICESat mission gauged ice thickness by bouncing a laser beam off the surface of the snow and measuring the time it took to return. But ICESat ceased operations last fall after six years, and its replacement is not due to fly until at least 2015. The European Space Agency's newly launched CryoSat-2 mission is taking up some of the slack with its own radar altimeter instrument. NASA is also flying research airplanes in the IceBridge mission over some regions of the Arctic.

Pulling all these views together will give polar scientists a much fuller picture of the sea ice situation. And all will be looking to see what this year's summer melt season brings, to forecast how much time they may have left to study the ice at all. ■

Explore more

- K.M. Golden. "Climate change and the mathematics of transport in sea ice." *Notices of the American Mathematical Society*. May 2009.
- National Snow and Ice Data Center's page on Arctic sea ice: nsidc.org/arcticseaicenews/
- Sea ice outlook: www.arcus.org/search/seaiceoutlook/

NASA/GODDARD SPACE FLIGHT CENTER SCIENTIFIC VISUALIZATION STUDIO

Sea ice's yearly retreat

Each September, polar scientists get the number they've been betting on all summer: how small the Arctic ice cap will get that year.

At the end of the summer melt season, sea ice covers only a fraction of the Arctic Ocean compared with the ice's winter reach. In September 2007 ice reached a record low, covering about 4.2 million square kilometers — about 23 percent less than the previous record minimum, in 2005. Few researchers had seen the 2007 record low coming.

So in 2008, scientists began putting together predictions for what the upcoming summer might bring. International teams of researchers submit to a central organizer their "outlooks," which include a number — how small they expect the Arctic ice cap to get that year — and a rationale for that number. Reports are due by June and updated monthly throughout the summer to incorporate information about changing ice conditions. This June will mark the third annual effort.

So far, the project has primarily shown how hard it is to predict sea ice cover. Many factors determine how much ice exists from year to year, from oceanic heating patterns to wind and water conditions that can either pile up ice into sturdy blocks or break it apart and flush it out of the Arctic Ocean basin.

For instance, all of the project teams underestimated how much ice would remain in September 2009. The median estimate was 4.6 million square kilometers, but the final number was 5.36 million square kilometers, in large part because of weather patterns in August and September that kept things chilly across large parts of the basin.

This spring, Arctic sea ice reached its maximum on March 31 (above), the latest date recorded for a maximum since satellite measurements began in 1979. The late maximum probably won't affect the September minimum much, since most of that ice is thin first-year ice on the southern fringes that will melt away quickly once temperatures rise, says Arctic expert Walt Meier of the National Snow and Ice Data Center in Boulder, Colo. "What really is key is how much of the thick ice we have," he says. "We have more thick ice than we did the last couple of years at this point." As of late May his team's predictions for the 2010 minimum had not been released publicly, but Meier says that this year's ice might look similar to that in 2009 — not the dramatic low seen in 2007.

Marika Holland, a climate modeler at the National Center for Atmospheric Research in Boulder, likens the forecasting exercise to the early days of predicting the El Niño climate pattern. Unreliable decades ago, El Niño predictions have improved to the point that today planners use them regularly.

The Arctic outlook project hopes one day to have similarly useful forecasts for sea ice. In the meantime, the project has started issuing a much smaller-scale forecast for regional use. The new "walrus outlook" predicts coastal sea ice patterns for the upcoming week, for use by native hunters. —*Alexandra Witze*