field. The heat of a magma ocean would frustrate the generation of a magnetic field in Io's molten iron core by erasing the temperature gradient that drives a dynamo. And Io's gravitational signature, which Galileo returned during its close passage, could reveal the unusually low density of a magma ocean. But everyone agrees that the clearest answer would come from an Io orbiter, which could probe for a soft, molten interior by measuring the rhythmic kneading of the satellite by Jupiter. Then a unique, albeit lifeless, ocean might join the club.

–RICHARD A. KERR

CLIMATE CHANGE

Will the Arctic Ocean Lose All Its Ice?

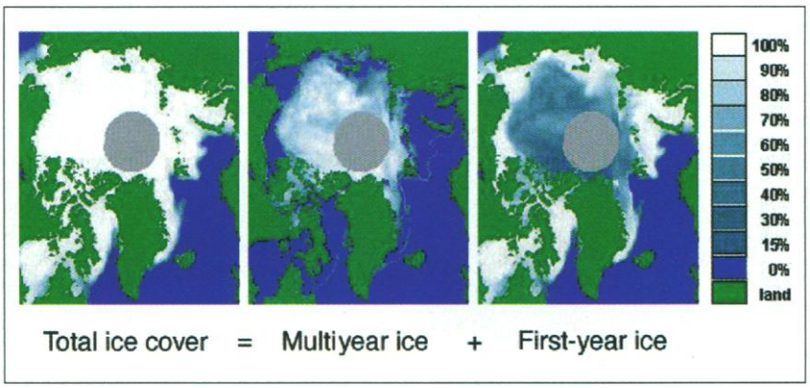
Miners have their canaries to warn of looming dangers, and climate change researchers have their arctic ice. The sea ice floating at the top of the world—enough to cover the United States—is highly sensitive to changes in the air above and the ocean below, and for several years Arctic watchers have been detecting what looked like slow shrinkage—a change they've read as a suggestive sign of global warming. But now they see warnings that their "canary" is in deep trouble and could expire in a matter of decades.

"Suddenly, all these different, relatively weak indicators [of arctic change] are making a coherent story that looks really intriguing," says polar climate researcher Douglas Martinson of the Lamont-Doherty Earth Observatory in Palisades, New York. The story, as updated in reports in this issue of *Science* and the 15 December issue of *Geophysical Research Letters*, tells of an arctic ice pack that is not only shrinking in area but rapidly thinning as well. The big question now is what's causing the shrinkage: natural polar climate fluctuations or global warming due to increasing levels of greenhouse gases. If it's all natural, the loss of arctic ice should eventually reverse, but if global warming is at fault, the entire ice pack will eventually disappear, with drastic climate implications for the Northern Hemisphere.

The decline of arctic ice had seemed real enough, though not yet alarming. By combining satellite observations and historical records of ice extent, various groups had found that the area covered by the ice in the summer has been decreasing by about 3% per decade during recent decades. At that rate, notes Martinson, it would take another 350 years for the Arctic Ocean to be ice-free in summer. The shrinking caught everyone's attention but remained tantalizing.

But polar researcher Ola Johannessen of the Nansen Environmental and Remote Sensing Center in Bergen, Norway, and his colleagues report on page 1937 that the arctic ice is undergoing a much more rapid change. As do all materials above absolute zero, ice emits microwave radiation, the exact spectrum of which depends on whether the ice is newly frozen or has thickened over a number of years. By compiling and analyzing satellite observations of these microwave emissions made from 1978 to 1998, Johannessen and his colleagues found that the area of multiyear ice had declined by 7% per decade during the 20-year period—twice the rate at which the total ice area has been shrinking.

Another change in arctic ice appears to be progressing at an even faster rate, according to the *Geophysical Research Letters* report. In that paper, polar oceanographers Andrew Rothrock, Yanling Yu, and Gary Maykut of the University of Washington, Seattle, compared two sets of measurements of polar ice thickness taken by U.S. Navy nuclear submarines. The first were made from 1958 to 1976 while on military patrol. The second were made in 1993, 1996, and 1997 during the Scientific Ice Expeditions program. Upward-looking acoustic sounders mapped the ice depth the way depth sounders map the sea floor.



A weakening heart. While the extent of arctic ice (left) is shrinking, the thicker ice frozen over several years (center) that forms the ice pack's core is wasting away even faster.

Overall, the Seattle team found, the ice over the deep-water Arctic thinned from an average thickness of about 3.1 meters to about 1.8 meters, or about 15% per decade. That's five times faster than the ice area has been shrinking. What's more, the ice thinned at every one of the 26 sites for which the researchers compared data. Overall, says Rothrock, the arctic ice has lost 40% of its volume in less than 3 decades.

"The current evidence is pointing to something going on" with arctic ice, says polar researcher John Walsh of the University of Illinois, Urbana-Champaign. If thinning continues at this rate, he notes, "there really are only a few decades before ice thickness reaches zero." That would convert the Arctic Ocean from a brilliantly white reflector sending 80% of solar energy back into space into a heat collector absorbing 80% of incident sunlight, with effects on ocean and atmospheric circulation extending into mid-latitudes. These could include shifts in storm tracks, says Walsh, with changes in precipitation.

However, adds Walsh, "there's quite a bit of debate about why" the ice is thinning and therefore whether it will continue to do so. Most fingers are pointing at the Arctic Oscillation (AO), an erratic atmospheric seesaw that alternately raises and lowers atmospheric pressure over the North Pole while lowering and raising it in a ring around the edge of the polar region.

Through its changes of pressure, the AO can change wind patterns and thus affect ice thickness, notes Rothrock. In its positive phase, to which it shifted abruptly around 1989, the AO pumps more warm air into the Arctic, tends to warm the water entering the Arctic from the North Atlantic, and blows more thick, multiyear ice out of the Arctic—all changes that should thin the ice. Although the AO, like El Niño, is a natural oscillation, some climate modeling has recently suggested that building greenhouse gases may have driven the AO to its current extreme (*Science*, 9 April, p. 241). "I'm going to wait and see," says Rothrock. "I would lean toward the view that this is a fairly extreme state [of the AO], and it will likely come back toward more normal conditions."

However, on page 1934, climate researcher Konstantin Vinnikov of the University of Maryland, College Park, and his colleagues suggest that increasing levels of greenhouse gases may be the prime mover behind the shrinking arctic sea ice. The Maryland team compared the observed ice loss and the ice loss in two climate models simulating the strengthening greenhouse. The chances that the losses seen since 1953 are just an extreme of a natural cycle and will swing back toward normal are less than 0.1%, they say. Whatever your faith in such model studies, says Walsh, "we've got a region to watch now."

–RICHARD A. KERR

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