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The Big Melt

No Escape: Thaw Gains Momentum

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Correction Appended

In 1969 Roy Koerner, a Canadian government glaciologist, was one of four men (and 36 dogs) who completed the first surface crossing of the Arctic Ocean, from Alaska through the North Pole to Norway.

Now, he said, such a trek would be impossible: there is just not enough ice. In September, the area covered by sea ice reached a record low. "I look on it as a different world," Dr. Koerner said. "I recently reviewed a proposal by one guy to go across by kayak."

At age 73, Dr. Koerner, known as Fritz, still regularly hikes high on the ancient glaciers abutting the warming ocean to extract cores showing past climate trends. And every one, he said, indicates that the Arctic warming under way over the last century is different from that seen in past warm eras.

Many scientists say it has taken a long time for them to accept that global warming, partly the result of carbon dioxide and other heat-trapping gases in the atmosphere, could shrink the Arctic's summer cloak of ice.

But many of those same scientists have concluded that the momentum behind human-caused warming, combined with the region's tendency to amplify change, has put the familiar Arctic past the point of no return.

The particularly sharp warming and melting in the last few decades is thought by many experts to result from a mix of human and natural causes. But a number of recent computer simulations of global climate run by half a dozen research centers around the world show that in the future human influence will dominate.

Even with just modest growth in emissions of the greenhouse gases, almost all of the summer sea ice is likely to disappear by late in the century. Some of the simulations, including those run on an advanced model at the National Center for Atmospheric Research in Boulder, Colo., show much of the summer ice disappearing by 2050, said Marika Holland, a scientist there who is working on the sea-ice portion of that model.

Of the various simulations, all done for an international scientific report on climate trends to be issued in 2007, the only ones that retain much summer sea ice in the Arctic by 2100 are those that assume global greenhouse-gas emissions are held constant at rates measured in 2000 - something that only five years later is already impossible.

The other models all produce an Arctic Ocean in summer akin to the "open polar sea" that was sought by oceanographers and explorers in the mid-1800's. "There would definitely be shipping along the Eurasian coast, and the polar bears would have some serious issues," Dr. Holland said.

The models are, of course, impressionistic views of a far more complicated Arctic reality, so their projections are uncertain. But what worries field scientists, who form their opinions based on empirical clues embedded in ice or recorded by thermometers, is that observations of change and evidence pointing to past patterns are agreeing with the models.

David Barber, an Arctic expert at the University of Manitoba, said emissions needed to be cut quickly to avert even greater damage. Skeptics who use the uncertainties to justify delaying such actions forget that uncertainty cuts both ways, and things could be far worse than forecast, Dr. Barber and others say.

"I wish we would have started 50 years ago, but to not start now would be a real tragedy," Dr. Barber said.

But, he added, it is important to accept that shrinking summer sea ice over the next century is inevitable and that humans need to adapt.

That inevitability presents a sticky problem for environmental groups, many of which have suggested that cutting greenhouse gases could save the polar bear and Eskimo traditions, both dependent on sea ice.

"Even if you would stop every engine right now, there is no escape unless you physically take the CO_2 out of the air again," said Henk Brinkhuis, an expert on past Arctic ecosystems at Utrecht University in the Netherlands. He added that this would have to be done on a vast scale, far beyond simply planting trees or the like.

"You may argue for a long time whether this process will take 20, 50 or 100 years, but it doesn't change the fact that it will happen," Dr. Brinkhuis said.

A Work in Progress

The emerging picture of great Arctic changes ahead comes from the interlaced efforts of the modelers in their climate-controlled computer rooms and field scientists with numb toes and frosted beards. It will long remain a work in progress. But the underlying trends are robust, many Arctic scientists

say.

Field work suggests that past Arctic warm spells, like a stretch through the 1920's and 1930's, were limited to certain regions, while the recent warming has largely progressed in concert with rising temperatures around the Northern Hemisphere - a sign of large forces at work, climate scientists say, not regional variability.

Field studies have also provided information on how energy flows from air to ocean and into melting ice, how melting ice freshens water and growing ice makes it saltier - all dynamics that have helped modelers refine their programs.

Recent expeditions on icebreakers have started building the first detailed picture of the communities of algae, plankton, small cod, seals and polar bears that form an ice-based ecosystem as tenuous as the ice itself.

In the virtual Arctic of computer simulations, thousands of lines of computer code mimic how ice, oceans and the atmosphere interact and are components of larger global models of earth's climate and oceans.

The models are the only way to test how the planet may react to various human actions. Because there is only one earth, there are no other options for such studies, given that the real earth is already well along in an unintended experiment - the rapid buildup of long-lived greenhouse gases.

Those who work in that realm have steadily improved their simulations. A decade ago, for instance, most depicted sea ice just as static reflective slabs, and almost all now replicate how ice is tugged by wind and ocean currents, Dr. Holland said.

The inevitability of summer ice retreats, she and other Arctic experts say, is a result of the nature of the climate system, which is something like a heavy flywheel. Once started, flywheels tend to keep going. Within a few decades, say many scientists focused on the region, the insulating power of greenhouse gases will dominate natural climate fluctuations, possibly for centuries.

And the flywheel in the Arctic moves faster than in other areas because the region amplifies change. The most obvious mechanism is the difference in how bright white sea ice and the dark sea act under sunlight. Ice reflects most of the solar energy striking it back into space. Water absorbs most of it.

A result is that each area of ocean exposed by melting ice soaks up heat, melting more ice, exposing more sea, soaking up even more heat - and so on, until the annual marathons held each spring on the floating ice near the North Pole are replaced by boat races.

Saving Greenland

Warming has already caused anger and confusion among native peoples on one hand and enthusiasm for new shipping routes among entrepreneurs on the other. But scientists are still grappling to describe what is going on. "You might call it the temperatization of the Arctic; we haven't really invented a word for it yet," said Charles Vörösmarty, the director of the Complex Systems Research Center at the University of New Hampshire and one of 21 co-authors of a recent article in Eos, a journal of the American Geophysical Union, about the changes.

The article grew out of several gatherings of Arctic scientists organized by the National Science Foundation over the last two years.

Titled simply "Arctic System on Trajectory to New, Seasonally Ice-Free State," it says, "There seem to be few, if any, processes or feedbacks within the Arctic system that are capable of altering the trajectory."

Those authors and many other experts have settled on the same picture of the region late this century: tundra retreats and forests spread; most sea ice disappears in late summer; coastlines wear away under the assault of wind-driven waves on waters that previously were sheathed in ice; permafrost turns to bogs; and ancient lakes that once sat atop permanently frozen ground drain like unplugged bathtubs.

Climatologists say the effects eventually could extend far beyond the sparsely populated north, contributing to climate and ocean shifts that could dry the American West and possibly slow north-flowing warm currents in the Atlantic Ocean that keep northern Europe milder than it would otherwise be.

The effects could also include a sharp increase in the rate at which seas are swelled by melting glacial ice and far greater warming as even more greenhouse gases, locked in permafrost and the Arctic seabed, are liberated by warming.

For example, American and Russian scientists studying lakes in northeastern Siberia recently reported that the melt of permafrost is generating methane, a potent greenhouse gas. In spots, so much methane is being released that roiling streams of bubbles prevent the surface from freezing even in the depths of the Siberian winter.

The most that can be expected, some climate scientists say, is to limit the human contribution to warming enough to forestall the one truly calamitous, if slow motion, threat in the far north: the melting of Greenland's ice cap.

Rising two miles high and spreading over an area twice the size of California, this vast reservoir - essentially the Gulf of Mexico frozen and flipped onto land - contains enough water to raise sea levels worldwide more than 20 feet.

In recent years, the ice sheets of Greenland have been building in the middle through added snowfall but melting even more around the edges in summer. Many Greenland experts say the melting is already winning out.

James E. Hansen, a scientist for the National Aeronautics and Space Administration who has been designing simulations of earth's climate for nearly four decades, is among those who say prompt cuts in emissions can avert a Greenland meltdown.

Dr. Hansen said that while the Arctic's amplifying effects, like the transition from white ice to dark water, are substantial, they still occur only when the region is feeling some big external warming influence, like the transport of heat from the rest of a greenhouse-warmed planet.

If prompt action is taken to slow growth in carbon dioxide releases, and other, easier efforts are begun to cut emissions of methane, soot and other sources of warming, he said, then it may be possible to retain some summer sea ice and prevent rapid deterioration of the Greenland ice sheet.

"It is physically and technologically possible, but there has to be a will to achieve it," Dr. Hansen said.

Other scientists are not as optimistic.

Fresh studies of ancient glacial ice and sea-floor sediments show that, if anything, the computer simulations projecting strong warming and ice retreats in the region over the long run may be substantial underestimates, Dr. Brinkhuis said.

"Everything we are seeing shows things can move more and faster than we think," he added, referring to geologic and glacial records of past Arctic changes.

The current increase in greenhouse gases, he continued, is similar to past natural changes that profoundly altered the world.

"We have not seen such fast carbon dioxide rises as we have now other than in extreme cases in the past," Dr. Brinkhuis said, including periods like one about 50 million years ago that turned the Arctic Ocean into a warm, weed-covered lake.

Confounding Turbulence

Dr. Brinkhuis and many other veteran Arctic researchers caution that there is something of a paradox in Arctic trends: while the long-term fate of the region may be mostly sealed, no one should presume that the recent sharp warming and seasonal ice retreats that have caught the world's attention will continue smoothly into the future.

"The same Arctic feedbacks that are amplifying human-induced climate changes are amplifying natural variability," explained Asgeir Sorteberg, a climate modeler at the Bjerknes Centre for Climate Research in Bergen, Norway.

Indeed, experts say, there could easily be periods in the next few decades when the region cools and ice grows.

The natural Arctic variability is shaped by basic geography and physics.

Near the Equator, climate is as predictable as the age-old trade winds that blow there, fueled by steady streams of sunlight and shaped by the planet's rotation. But toward the poles - and particularly the North Pole - everything gets stirred up, said David Atkinson, an atmospheric scientist at the International Arctic Research Center of the University of Alaska at Fairbanks.

The region has just about the most turbulent climate on earth, he said, one in which conditions are shaped by slow cycles of temperature changes in the Pacific Ocean, pulsing shifts in areas of high and low barometric pressure over the pole and North Atlantic, and fundamentally chaotic flutters in the atmosphere.

The North Pole climate is even more variable than that at the other end of the earth in part because the Northern Hemisphere is a mix of continents and islands topped by the small but dynamic Arctic Ocean, which is partly ice covered.

The Southern Hemisphere is mostly ocean with a permanently ice-sheathed continent at the pole.

Because of that natural turbulence, a significant camp of Arctic specialists say they are not convinced that humans are driving the changes in the North.

"It's definitely true that the level of variability in high-latitude regions is huge, and trying to separate this from a human-induced trend is very difficult," said Igor Polyakov, another expert at the school's Arctic research center.

In the short run, the natural fluctuations will most likely sustain those on both sides of the debate over how to respond to global warming, with cool years embraced by skeptics and hotter ones by proponents of cutting the heat-trapping gases, said Dr. Richard B. Alley, a geoscientist at Pennsylvania State University.

But he and other scientists say it is clear that in the long run, the Arctic will get warmer, a conclusion at the heart of the Arctic Climate Impact Assessment, a report commissioned by the eight Arctic nations and released last year.

Dr. Koerner, the Canadian glaciologist, pointed out on time scales of millenniums, the recent warming has even trumped a long cooling trend.

"The warming trend is even more significant," he said, "because it's not on a flat background but something that maybe should be getting colder."

For now, the modelers and field researchers continue to work at least in parallel, if not in tandem.

For example, Dr. Holland, a modeler, has never seen the real Arctic. She said a colleague who spends most summers slogging through ponds of meltwater on Arctic Ocean floes recently proposed creating a program called "Take a Modeler to the Arctic." The proposal was only half in jest, she said.

Just two weeks ago, she and that researcher, Donald Perovich, renewed the discussion, with fewer chuckles.

"I'd like to see what it's like before it actually disappears," Dr. Holland said.

Craig Duff contributed reporting from Churchill, Manitoba, for this article.

Correction: Oct. 27, 2005, Thursday:

A map in Science Times on Tuesday showing projected warming in the Arctic over the next century, with an article about scientists' assessments of the trend, reflected erroneous temperature conversions. The Fahrenheit figures shown on the key should have gone from 0 to 10.8 degrees (0 to 6 degrees Celsius), not from 0 to 3.3.

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