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ROUGH SEAS: North of Russia, near the Arctic islands of Franz Josef Land, open waters—which had more ice cover in the past—toss up choppy waves.

OCEANOGRAPHY

waves of truction

Scientists chase towering seas that smash Arctic ice, with far-flung effects on climate and ecology

By Mark Harris

IN BRIEF

Arctic sea ice has been melting faster than predicted by global warming models, puzzling scientists.

Giant waves, never seen before, may be the reason. A little ice melt gives waves room to grow large and powerful.

The large waves can smash still more ice as they crash around, creating more open water and more waves.

Newly opened Arctic seas may affect faraway weather patterns, erode coasts and challenge national security.

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THE SUMMER OF 2014 WAS A STRANGE ONE IN THE CHUKCHI SEA. THE ARCTIC WATERS, historically icebound much of the year, were oddly free of ice. There was so little ice that 35,000 walruses had beached themselves on a northwest Alaska shoreline after failing to find floes to feed from. One morning in September, oceanographer Jim Thomson was on a research trip onboard the vessel *Norseman II,* hundreds of miles from land, when he noticed something else that was strange: some of his shipmates were seasick.

Nausea might sound pretty ordinary for a trip to the high seas but not out here, where the Chukchi meets the Beaufort Sea. This remote area usually has no room for waves to build. Now there was open water, and the waves were huge—15-foot rollers that tossed the ship around and exploded over its decks. The sea was so rough that the captain could not safely sail against the waves and had to run in front of them. While Thomson, a seasoned sailor, watched his fellow researchers stumbling around the ship, looking as if they were about to lose their lunch, he was reveling in the stormy weather. He had come to hunt waves, and here they were.

"These were bigger than had ever been measured or talked about or conceived of in the Arctic," Thomson recalls. A few months earlier he had deployed a small fleet of aquatic drones to monitor the seas; that day he was trying to pick one up. "In fact, the largest wave heights we recorded for the whole year were about six hours before we recovered the robot," he adds.

These waves may be the answer to an important and troubling mystery: Why is Arctic ice vanishing so fast? Climate models, driven by measurements of global warming, had projected a slower rate of shrinkage. Either the models were wrong, or something else was going on. That something, Thomson and other scientists now believe, had to do with waves. Climate-triggered melting gave waves extra room to grow, which let the rollers take over, pounding away at the ice pack and splintering it into nonexistence. When Thomson put out similar robotic buoys in 2012, one of them was tossed by a towering wave that lifted the buoy 25 feet up.

Gigantic, new waves in this region can have far-flung and world-changing effects. Arctic waters circle the pole, going from the Beaufort and Chukchi seas above Canada and Alaska, to the East Siberian, Kara and Barents seas north of Russia, to the Norwegian and the Greenland seas atop the Atlantic. In this vast area, ice cover might affect not just walrus habitat but the courses of ocean currents and even the atmospheric jet stream, influencing climate thousands of miles away. And with ice no longer protecting the land's edges in the region, fragile permafrost—which makes up a big portion of coastline—may also be in danger.

These consequences are what brought Thomson and 100 other researchers, along with the most sophisticated remote-sensing network ever deployed in cold waters, back to the Arctic in 2014. Their mission was a multimillion-dollar experiment to uncover what the appearance of giant waves might mean for the future of the world's most mysterious ocean.

NORTHERN EXPOSURE

RESEARCHERS HAVE KNOWN for years that they were missing something critical about the Arctic. No matter how scientists crunched the numbers, the annual partial breakup of the ice cap was happening faster and farther than any model predicted, even allowing for extreme versions of global warming. In 2007 Julienne C. Stroeve, a climatologist at the National Snow and Ice Data Center in Boulder, Colo., took note of this in a paper, writing that none or very few of the Arctic simulations used by the Intergovernmental Panel on Climate Change were predicting the ice retreats seen in the real world. Even after tuning the models, Stroeve says, the shrinking ice still outpaces predictions: "The recent decline is still outside the average of all the models. They aren't really picking up on what's happened."

Accurate Arctic climate models are critical. Scientists at Pacific Northwest National Laboratory think that less sea ice in the Arctic means heat energy that is usually trapped underneath this ice can escape into the atmosphere. This rising heat can disrupt the jet stream, the swiftly moving high-altitude air current that makes it quicker to fly from west to east in the U.S. than the other direction. Some scientists believe that the jet stream acts as a barrier that prevents frigid Arctic air from moving south and that changes to it can cause extreme "polar vortex" weather events such as those that have frozen East Coast cities in the U.S. during the past two winters.

Scientists at the Woods Hole Oceanographic Institution have measured an increasing volume of freshwater in the Beaufort Sea as the ice thins and retreats. There is now 25 percent more freshwater than there was 40 years ago. If this cap of freshwater were to escape into the North Atlantic, it could alter ocean currents significantly. The cap did something similar in the 1970s, for reasons that are still unknown, spilling Arctic ice south and

PRECEDING PAGES: ANDY MANN *National Geographic*

SEA WITHOUT WAVES: When dense sea ice covers the Arctic's Beaufort Sea, the water stays flat and calm. It is, however, difficult for ships, even this U.S. Coast Guard vessel, to move about.

disrupting currents that help to balance temperatures in the region. Some scientists believe that similar perturbations have driven extremely rapid climate changes in the past, such as an event around 12,000 years ago that warmed Greenland's ice sheet by around eight degrees Celsius over just a few decades.

Vanishing ice is also accelerating current coastal erosion in the Arctic. Permafrost coasts, where permanently frozen subsoil meets open water, make up around one third of all the coastline on the earth. "The only thing that holds these coasts together is the ice, and they may erode very fast when they are not protected by sea ice," says Hugues Lantuit, a geomorphologist at the Alfred Wegener Institute in Germany, a center for polar research. Some coasts along the Beaufort Sea are already retreating at up to 100 feet a year.

This erosion can wipe out human settlements, devastate ecosystems, cause land to sink, and contribute to ocean acidification and global warming. As permafrost melts, it releases carbon from plants, animals and microorganisms that had been frozen within. This organic matter will eventually decay and become a source of carbon dioxide and methane, greenhouse gases that can also acidify the ocean and make it less hospitable to sea life.

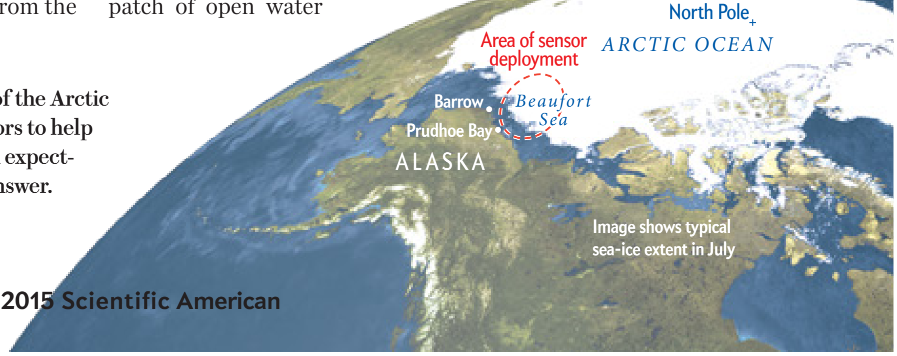
Big businesses would like a better idea of what is happening to the ice as well. Oil and gas companies spy new opportunities for drilling in previously frozen waters. And if the amount of seasonal melt can be accurately predicted, shipping firms could use the fabled Northwest Passage to cut journey times from the Pacific to the Atlantic by a week. The missing ice has also attracted the attention of the U.S. Navy, not least for the security implications of having a brand-new ocean open up on the country's northern border.

All in all, there are many pressing reasons to figure out why the ice has been going away.

Thomson suspects that big waves and their ice-destroying power could explain why predictions have not matched up with reality. "Until now, waves have not been included in a systems model that takes the ocean, the atmosphere, the weather and the sea ice, then couples them all together to make a better forecast," Thomson says. "The mechanical process is simply missing." Lantuit, the coast expert, says that although wave impacts are not well understood, they could explain his changing maps. "There isn't yet a good model of wave impacts on permafrost coasts," he notes. "But as a rule of thumb, if you get bigger waves, you can expect more erosion."

HUNTING THE BIG ONES

ALTHOUGH WAVES have been absent from the various models, scientists have long known what crashing seas can do to even the toughest ice. Elizabeth Hunke models oceans and sea ice for Los Alamos National Laboratory. On a trip in 1998 to the other side of the planet, Antarctica, she came across a rare patch of open water



EXPLORING THE MELT ZONE: In 2014, in an area of the Arctic northeast of Alaska, scientists deployed a network of sensors to help them figure out why sea ice has been vanishing faster than expected. Large, ice-smashing waves might be a big part of the answer.

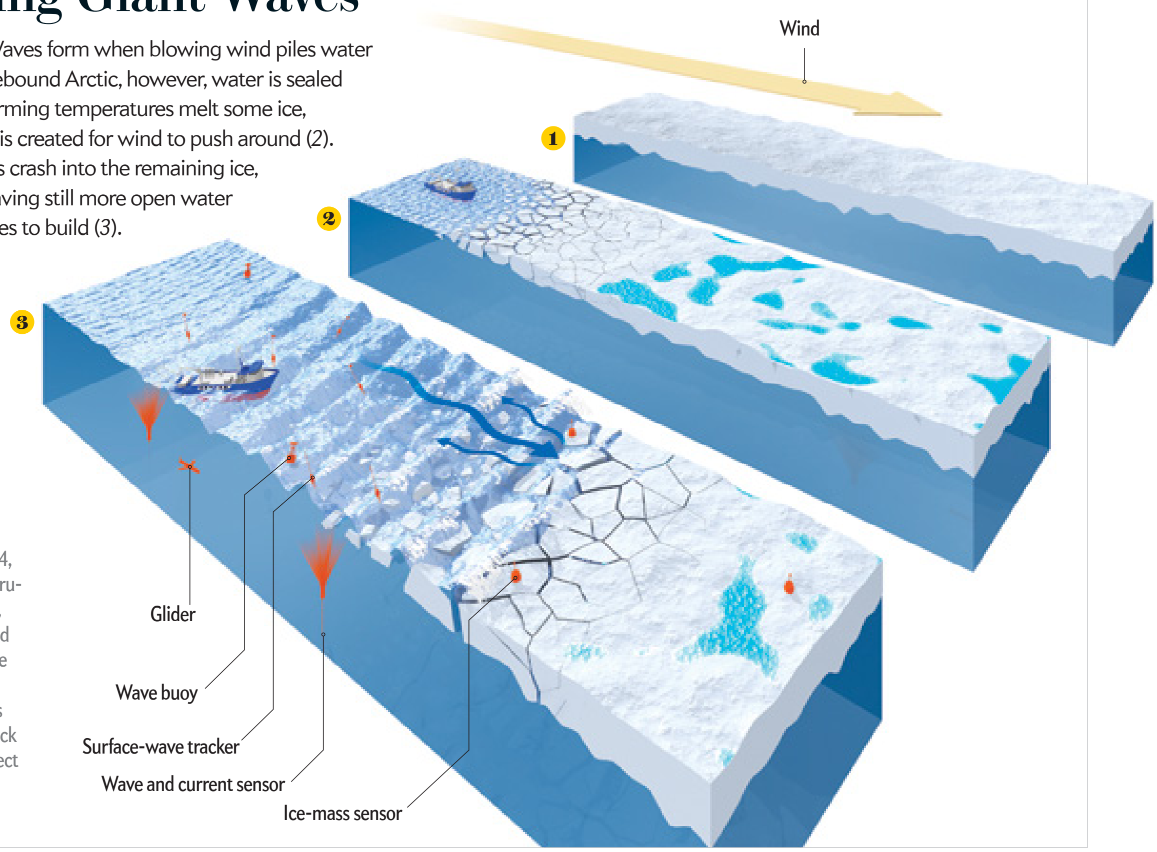
Map by XNR Productions

DANIEL J. COX *Getty Images* (ice); SOURCE: NASA VISIBLE EARTH (*globe data*)

THE ICE EFFECT

Making Giant Waves

Wind and water: Waves form when blowing wind piles water ahead of it. In an icebound Arctic, however, water is sealed away (*1*). When warming temperatures melt some ice, a bit of open water is created for wind to push around (*2*). The resulting waves crash into the remaining ice, shattering it and leaving still more open water for even larger waves to build (*3*).



To trace ice-wave connections in 2014, scientists used instruments shown here, including buoys and trackers to measure wave dimensions, underwater gliders to follow the ice pack and sensors to detect ice thickness.

near the Filchner-Ronne Ice Shelf in the Weddell Sea. "I watched waves batter sea ice that had been fastened to the shore for years, decades or perhaps even centuries," Hunke says. "Although the ice was really thick and hard to break off, that's just what the waves were doing."

But with no one envisioning giant waves in the Arctic, scientists had not thought to seek them out or factor them into their calculations. The startling measurements made by Thomson's lone buoy in 2012 changed all that.

It caught the eye not only of oceanographers but of the U.S. Office of Naval Research, which had already decided it was worth $12 million to find out where Arctic ice was going and launched a project called the Marginal Ice Zone (MIZ) program. Last summer wave hunting became an official part of the research.

The project brought together more than 100 international scientists in the most ambitious experiment ever to observe the seasonal breakup of the Arctic ice sheet. In years past this event would have started icebreakers churning across the ocean surface, submarines roaming the depths and satellites soaring overhead. In 2014, however, it meant small ships, short expeditions and lots of robot drones. Autonomous robots can now go places that humans can only dream of, gathering data 24 hours a day, without rest or relief.

In the spring of 2014, just over a year ago , scientists flew onto the thick, frozen ice of the Beaufort Sea and installed dozens of instruments along a 240-mile line running north from around 73 degrees north latitude toward the pole. These devices gauged the thickness of the ice, the temperature and composition of the water below it, and the weather above. The instruments were buoyed by flotation, so as the ice gradually broke up during the summer, dunking them into the chilly ocean one by one, they continued to gather water and weather data.

In late July, Thomson and five other scientists began deploying more sophisticated members of the automated team from a small converted fishing boat, the research vessel *Ukpik,* in the Beaufort Sea. At this time of year, the sun never sets, casting an endless wan light over a choppy sea and glinting floes. The scientists were possibly the farthest north mariners in the world at the time and more than 100 miles away from the nearest settlement. Despite the occasional distant spout of a bowhead whale, this region of the Beaufort is a desolate place.

What the researchers lacked in human company, they made up for in robotic companionship. They were preparing several different types of drones for work. Some were Thomson's standard wave-sensing buoys, similar to the one he moored nearby in 2012. The others were far more complex: Seagliders, six-feet-long torpedo-shaped underwater drones that propel themselves through the water, steering with a pair of adjustable wings. Each Seaglider has an external swim bladder that can be inflated to make it lighter than water or deflated to allow the robot to sink. A Seaglider can cover up to 12 miles a day, moving up and down in long, graceful arcs.

SCIENTIFIC AMERICAN ONLINE Watch scientists use aquatic robots to track Arctic ice and waves at ScientificAmerican.com/may2015/arctic-waves

Illustration by Bryan Christie

A powerful battery keeps each robot running for 10 months and helps to steer the drone by being tilted left or right as it glides through the water. When a Seaglider reaches the top of its swooping flight, it pokes its nose briefly above the waves like an inquisitive seal. Then it can get a GPS location fix, beam data up to waiting satellites and receive new instructions. Four Seagliders were deployed and spent two months ranging back and forth between open water and the ice sheet, measuring the turbulence, temperature, salinity and organic materials in the water.

When the Seagliders were under the ice for extended periods, they were cut off from their satellite watchdogs. To keep them connected, the scientists employed a third type of drone, surface travelers called Wave Gliders . The Rube Goldberg–looking Wave Gliders, which are powered by solar panels and the motion of waves, run right up to the edge of the ice and send acoustic signals to the submariners. Lee Freitag, an engineer at Woods Hole, developed a system to broadcast low-frequency sound signals to the Seagliders, relying on reflective layers underwater to bounce the sounds over long distances. (These are the same kind of layers, created by changes in water density, that allow whale songs to traverse entire oceans. The scientists chose different layers and frequencies from those used by resident cetaceans to avoid interfering with the animals.) The signals relayed latitude and longitude information to the Seagliders, along with instructions from the researchers.

This large-scale robotic approach has several advantages over traversing the high latitudes onboard an icebreaker. First, the robots let scientists cover a wider area. Icebreakers are limited to a single path, often cruising in one direction while the action is happening hundreds of miles away. The Wave Gliders and Seagliders, following directions from their handlers, can swerve to track every twist and turn of the ice as it succumbs to the sea.

There is another plus: the robots needed only a small mother ship, the *Ukpik*. "The *Ukpik* is small enough that we can maneuver in," Thomson says. "One of the biggest problems with a traditional icebreaker is that it's just too big. It's a bull in a china shop, destroying the very waves I'm trying to measure."

One day on the *Ukpik,* while leaning against the ship's rail after helping the crew drop a pair of Wave Gliders into the water, Thomson talked about how waves evolve. "To make waves, you need wind," he said. "Given wind, you need two things: time and distance. If you have more space, you'll make bigger waves, and you'll get the same with a longer-length storm. Really big waves come from having both."

In the springtime, even during the warmest years, most of the Arctic is still locked in ice. By the end of summer it has a surface area of free water more than twice the size of the Mediterranean. The more open water, or "fetch," you have, the larger waves will grow. The wind pushes water ahead of it, and longer fetches give more water time to pile higher.

When the water is free of ice, it also absorbs more heat from the sun—ice would reflect it away—and warming water heats the air, which can create more wind. If conditions are right, this combination can break up nation-sized areas of ice in a matter of days. That, of course, creates still more open water, in a feedback loop that makes it easier and easier for big waves to form.

What remains unclear is exactly how much each element in this loop contributes to the ice breakup and whether waves can slow the ice from re-forming as autumn closes in. For that, scientists need to understand more about the way that waves and sea ice interact.

BREAKING UP THE PACK

AFTER LEAVING THE DRONES in July, the *Ukpik* encountered a wide pack of sea ice, ranging from small chunks to looming hummocks that summon memories of the berg that sank the *Titanic* in 1912. It was perfect wave-hunting ground for Thomson. He leaped up to prepare a buoy. The ship stopped outside the ice pack for him to throw one overboard, then picked its way gingerly into the pack to deploy another.

The difference between the open sea and the ice pack was obvious as the ship moved in. In open water, the sea was rough and choppy. The moment the *Ukpik* reached the first small pieces of ice in the water, the chop faded to a low, smooth swell. And by the time the ship puttered a few hundred yards farther in, bumping and skirting some bigger chunks, there was nothing more than the faintest tremble in the glassy water between them. "The ice filters the waves such that only the longest waves make it the farthest in," Thomson says enthusiastically, carving a perfect tubelike breaker in the air with his hands. One of the things he wanted to learn was how much of this filtering came from an effect called scattering and how much came from another process known as damping.

Scattering would mean that the ice is simply moving the wave energy around without absorbing it, like a prism scattering light. Damping would mean that the wave is passing energy to the ice, moving it and breaking it up. A damping effect would cause the most damage to the pack. For all the drama surrounding house-sized waves out to sea, the centimeter-scale measurements being made here could do the most to improve Arctic systems models in the years ahead.

But what Thomson has already found makes the "more waves to less ice to even more waves" cycle plausible, according to W. Erick Rogers, an oceanographer at the U.S. Naval Research Laboratory. "This feedback loop seems to be an important mechanism for understanding sea-ice extent in the earth's future, warmer climate," he says.

As the *Ukpik* cleared the drifting ice and headed back to port, the ship was approached by a small flat-bottomed boat piloted by an Inuit fisher and his grandson from a nearby settlement, who gave the research vessel's crew some freshly caught fish for supper, three plump Arctic char. Arctic sea ice is beginning to get attention in the rest of the world, but it is these communities—and wildlife such as polar bears, seals and whales and microbes buried in the permafrost—that are already feeling the impact of the shrinking ice and the ever growing waves. SA

MORE TO EXPLORE

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