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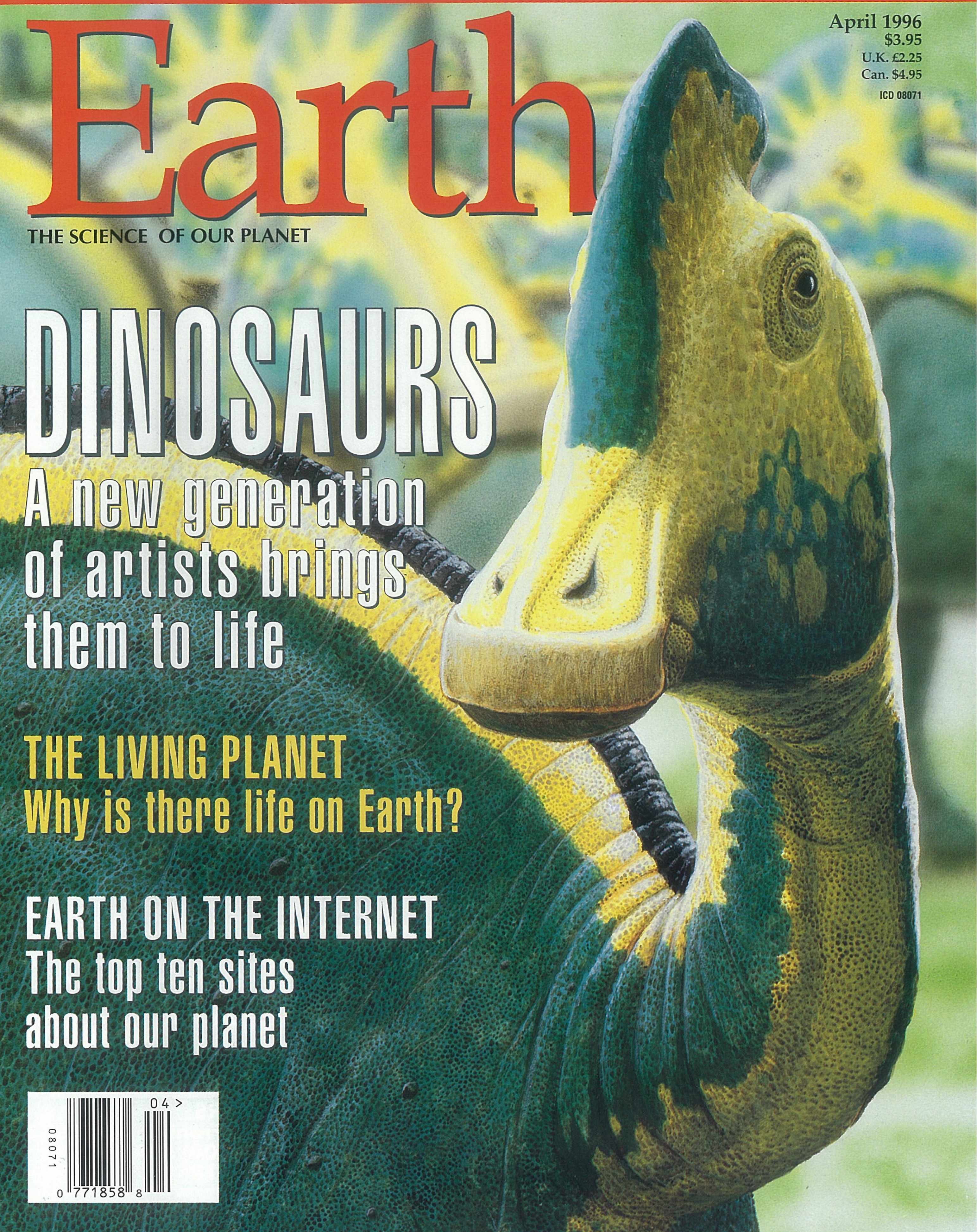

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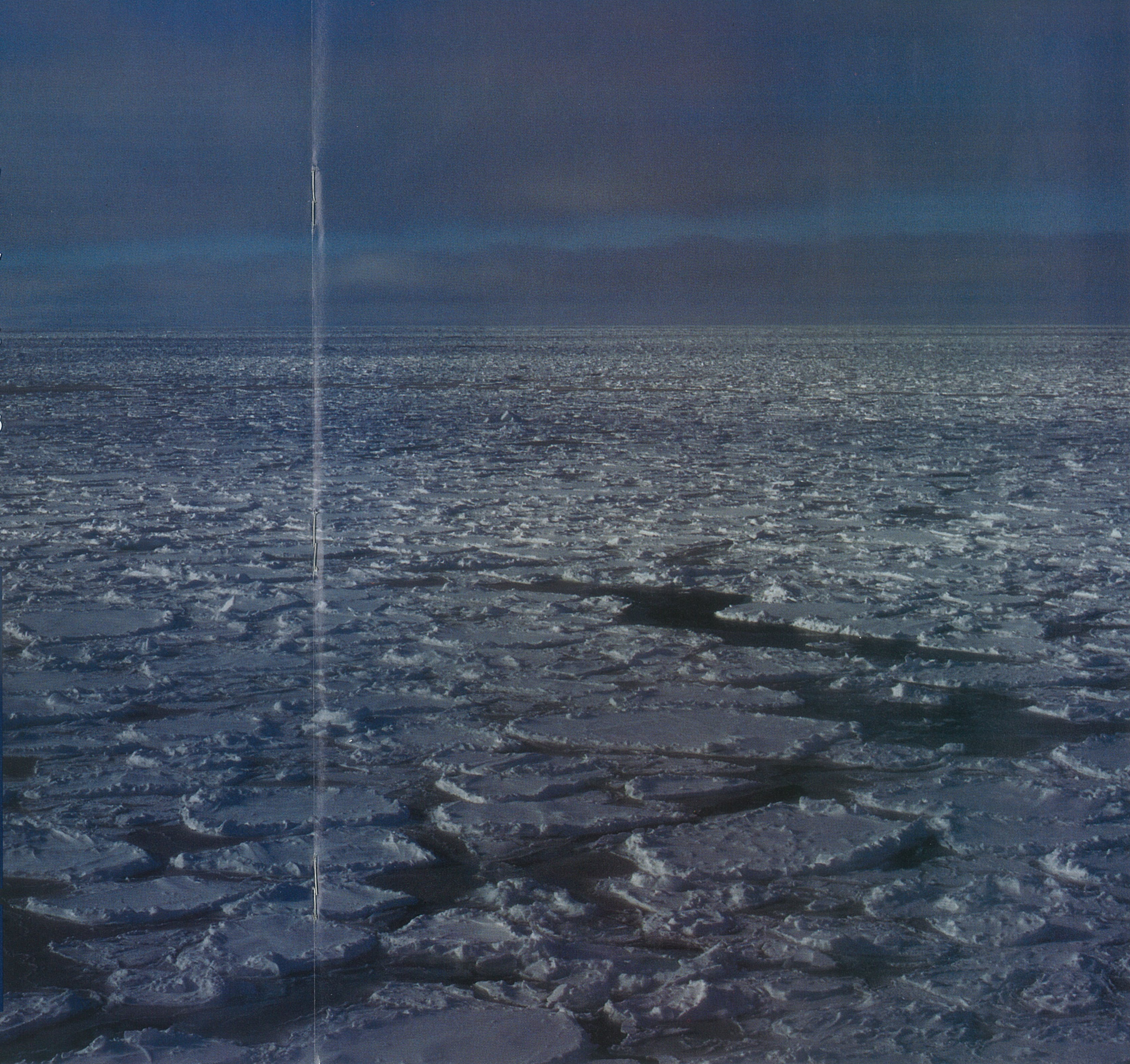
On Thin Ice

Braving Earth's most hostile environment, scientists have ventured into storm-tossed winter seas to pursue an abundant object: Antarctic sea ice. Although only inches thick, this humble substance plays a critical role in shaping our climate.

By Ruth Flanagan and Tom Yulsman



In autumn, sea ice grows around the Antarctic continent at the astonishing rate of 22 square miles per minute. In the early stages of freezing, pancake-shaped patches of ice form (right). Even after freezing completely, the sea ice is quite thin, typically measuring only 16 inches thick — thin enough for researchers like the ones above to drill through.

Photo courtesy Steve Ackley. Inset photo courtesy M. Naomi Darling

Against the black winter sky, deep in the frozen reaches of Antarctica's Weddell Sea, it was an incongruous, almost surreal sight. A bright orange icebreaker, the *Nathaniel B. Palmer*, sat anchored in an ice floe, lit up like a Christmas tree in blowing snow. Off the ship's starboard side, a tiny "town"— four research huts on runners — hunkered down in the growing storm. An electric cable ran along "Main Street," a path marked by red flags and lights, to power the scientific instruments inside the huts.

Courtesy Vicky Lytle

Oddly cozy as it looked, this was one of the most dangerous places on Earth. For the only thing separating the research station from the 12,000 feet of frigid water below was a layer of sea ice a mere 16 inches thick. Unlike the freshwater icecap that rests thousands of feet thick over the continent, Antarctic sea ice is ephemeral and fragile. It forms in the austral autumn, when the Southern Ocean around Antarctica freezes at a rate of 22 square miles per minute. By winter it covers nearly 8 million square miles, an area twice the size of the United States, but in a layer generally no more than three feet thick. By summer most of it has disappeared.

In winter, the Antarctic sea ice often looks like a frozen landscape that stretches solid and certain from here to eternity. But it can quickly split apart, a very real danger that the researchers on "Main Street" knew well. So when one of the scientists noticed an inch-wide crack between one of the huts and the ship, the two people on safety duty quickly left their dinners to take a look. "We followed it for quite a way," says Steve Ackley, a geophysicist from the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire. The crack didn't seem to be getting bigger.

Just to play it safe, they walked to the hut at the end of the line, where Robin Robertson from Oregon State University was working, and asked her to come back to the ship. By the time the three had trudged back to the crack, heads down into the wind, it had opened to 12 inches. Oceanographer Tim Stanton from the Naval Postgraduate School in Monterey, California, hauled his instruments from the water and shut down the computers. The four then leapt across the ever-widening gap in the ice and moved quickly toward the ship. That's when, according to Ackley, "all hell broke loose."

Cracks splintered the ice around the ship's stern. The gangway tipped precariously. One of the poles holding the power cable eventually snapped as ice surged around the ship. A winch cable attached to the *Palmer* stretched nearly horizontally; it came precariously close to splitting apart and dropping a $50,000 high-tech water sampler into the ocean. Three snowmobiles rocked on the heaving ice and were about to embark on a two-mile vertical journey, no fuel necessary.

Fortunately, the ship's crew knew what to do. They slung a large basket over the side to rescue the people still on the disintegrating ice. Then as the *Palmer* lurched away from the camp, the scientists severed the electric cable to the huts: There was no time to unplug it, and no one wanted to risk trailing the instruments and equipment behind the ship. Captain Joe Borkowski sprinted to the bridge and began gingerly maneuvering the ship to move the winch cable perpendicular to the water so that the water sampler could be brought up. Three people jumped back in the basket to rescue the snowmobiles. One machine was hauled aboard; the other fell into slush but was pulled out moments before it disappeared. A researcher made it to the third snowmobile, fired it up and jumped ridges burping up from the ice floe to move the vehicle onto solid ice. He then leapt into the basket and was hauled to safety.

Courtesy Ken Golden

In the Southern Hemisphere's winter of 1994, scientists participating in the ANZFLUX project ventured into the Antarctic sea ice aboard the icebreaker *Nathaniel B. Palmer*. They went there to gather new information about the links between Antarctic sea ice, global ocean circulation and climate. In the photo on the facing page, project members sweep snow off the ice to prepare for experiments. At left, a diver gets ready to take the plunge into the icy water near the ship. And below, an ANZFLUX member finds reason to smile despite leaden skies and frigid temperatures.

Courtesy Gary Kuehn

"It was just incredible, instantaneous destruction," says Doug Martinson, an oceanographer at Lamont-Doherty Earth Observatory in Palisades, New York.

It might seem perverse that sensible researchers would willingly subject themselves to such an ordeal. Yet these were precisely the kinds of conditions they had traveled so far to study. The 1994 expedition, called the Antarctic Zone Flux Experiment (ANZFLUX), was the first detailed study of the complex interactions between the atmosphere, the ocean and the ice in the Weddell Sea — interactions that are critical in regulating the global climate system. And the storms, and even the cracks in the ice, all play a part in the process.

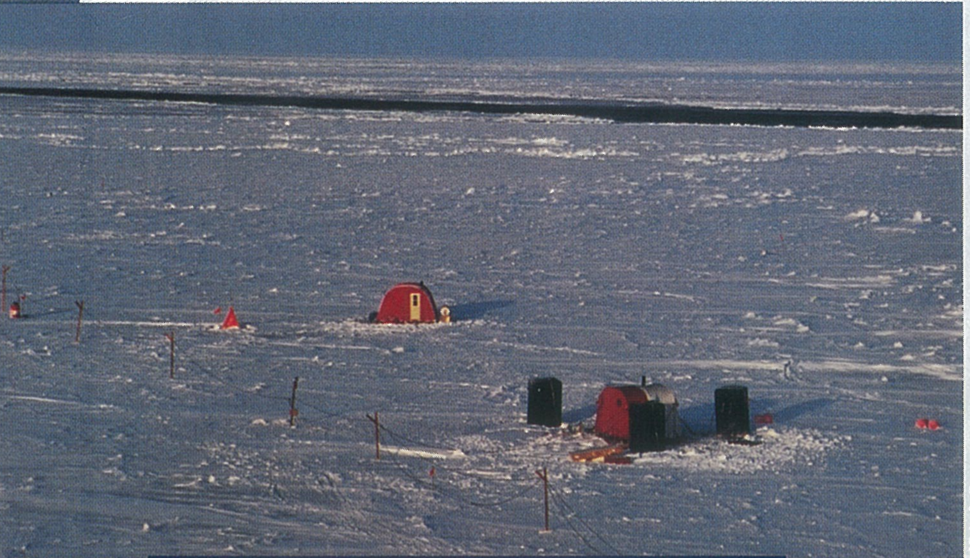
For this particular perilous spot is one of the few places on Earth where heat from deep in the ocean dissipates at the surface. This in turn helps send ocean currents circulating across the globe. Part of the researchers' goal was to find out just how much heat escapes from the Weddell. But they also came to study the sea ice, whose very fragility is the source of its strength. By alternately growing and disintegrating, the ice keeps the ocean and atmosphere in a state of dynamic balance. It may even buffer the environment from some of the potential effects of human-induced climate change.

One can view the interaction in the Weddell as an intricate dance performed by ice, air and oceans or as a sometimes violent drama. But oceanographers see it mainly as a demonstration of thermodynamics: Earth finding a way to transfer its heat. Thermodynamics requires that heat move from warmer regions to colder ones. The climate system carries this out by sending heat from the sun-soaked tropics to warm the poles.

Much of the heat that warms the poles gets there by traveling "air mail," simply riding through the air. But heat can also travel by sea. In fact, the ocean transports one-third to one-half of the heat destined for the poles. And that stored heat is willing to take a long, difficult voyage to get where it needs to go.

Getting heat to Antarctica is no simple task. A giant current called the Antarctic Circumpolar Current encloses the continent and the surrounding frozen ocean like a moat, preventing warm surface currents from getting through. "The warm surface waters can't flow directly to the coastline of Antarctica. So what happens? This is what is so amazing about this Earth," Martinson explains. "Earth finds a way to get the heat down there."

Much of the heat that ultimately dissipates in the Weddell originates in the Pacific Ocean. Ocean currents move surface water from the tropical Pacific toward the Atlantic. Along the way, the water is heated by the sun. Once in the Atlantic, the warm water is carried by the Gulf Stream and other currents into the North Atlantic. Since the air there is colder than the surface water, heat streams out of the ocean, warming the atmosphere. By the time the currents reach into the Nordic seas, they have played themselves out. The water still contains heat, but at a few degrees above freezing it is too cold and too dense to remain at the surface. So it sinks deep into the ocean to begin a long odyssey south. It is now part of a great conveyor that flows all the way to Antarctica.



Courtesy Vicky Lytle

Courtesy Ken Golden

While conducting their research, some ANZFLUX scientists lived on the ice in small huts crammed with scientific equipment.

Before it reaches the Weddell, however, the deep water gets sucked into the Circumpolar Current — a time-consuming detour indeed. There it spins round and round, mixing with water from the Indian and Pacific Oceans, slowly spiraling inward and upward. Finally, several years, even decades later, it penetrates the interior and reaches the Weddell. It now lies 200 meters below the surface. What brings it up the rest of the way? The answer helps explain why the Weddell — and its sea ice — are so unique.

In most other parts of the world, the water column is stable: A lid of fresher or warmer, and consequently much lighter, water caps the layers below. This lid prevents the deep water from rising to the surface. But in the Weddell, the density difference between the surface layers and the deep layers is exceedingly small. The tiny density difference puts the water column in precarious balance. And sea ice is one factor that can tip that balance.

When sea ice forms, it squeezes out salt and ejects it into the underlying surface water. This increases the density of the surface water, forcing it to sink. The water below it rises up to fill the void. Storms also help the deep water rise by mechanical means. Even an ordinary Antarctic storm can pack hurricane-strength winds, which send the ice clipping across the water surface at some 30 inches per second. Since the ice bottom is jagged, this movement jostles the water like swizzle sticks in a cocktail, stirring up the deep water. Once the heat from below has risen close to the surface, it may then dissipate by melting the ice from below. (This helps explain why Antarctic sea ice can be precariously thin.) Or the heat can dissipate an easier way, thanks to the changes in wind direction that storms bring. These changes wrest the ice open, forming cracks, which allow the heat to escape directly into the air.

Taken together, such exchanges between winds, water and ice may seem messy and chaotic. But the Weddell is a system in exquisite, dynamic balance. Martinson theorizes that the opening and closing of cracks ensures that heat is released to the atmosphere at the same rate it wells up from the bottom. If too much heat is released during a storm, for instance, the surface water cools quickly. This in turn causes the cracks to freeze over, shutting off some of the heat loss. In short, the atmosphere always gets just what it "needs" from the ocean.

What does the ocean get in return? Just what it needs to keep the conveyor of deep currents moving. When the deep water dissipates its heat at the surface, it cools enough to sink. It then moves toward the Antarctic continental shelf. Through a complex set of processes, it sinks further and begins a long journey back north. Eventually, the cold water fills the deep ocean basins, and then slowly rises up to the surface. In the tropics, the water is heated by the sun and starts its journey to the North Atlantic to start the cycle all over again. In 1,000 to 2,000 years, it's back in Antarctica.

The ANZFLUX cruise was partly an effort to confirm this broad picture. Before then, scientists had only inferred that a great deal of heat must dissipate in the Weddell. No one had ever measured the amount, which is an elusive figure to obtain. A few scientists questioned whether it was happening at all.

The team's findings put any doubts to rest. The researchers measured a release of 40 watts per square meter of heat on average at their first study site and a whopping 100 watts per square meter during a storm — enough to light an incandescent light bulb on every square meter of the surface. By contrast, only two watts per square meter is released through the much thicker sea ice of the Arctic Polar Basin, an environment once thought to be similar. These findings suggest that the Weddell is indeed a critical switchpoint in the larger climate system.

Courtesy M. Naomi Darling

Storms with hurricane-force winds are common in the seas surrounding Antarctica. In the picture above, wicked winds kick up the snow while scientists work on the ice.

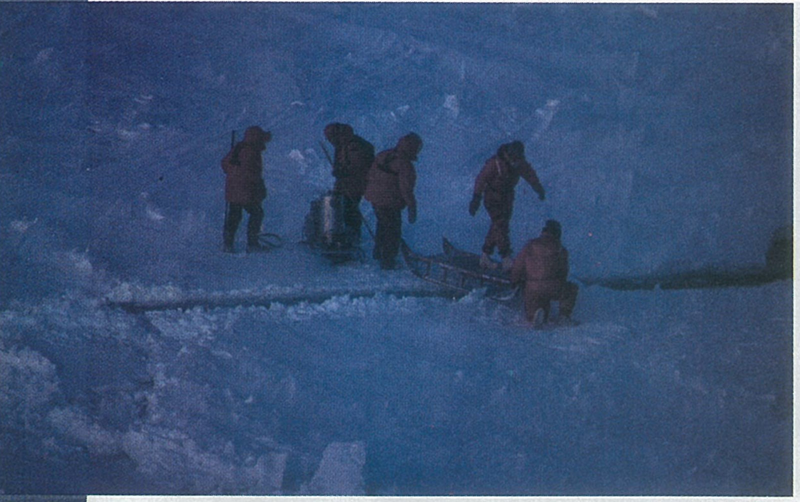
Courtesy Steve Ackley

During the ANZFLUX project, changing wind directions from a storm ripped open cracks called leads in the ice, imperiling the research huts and the scientists within. In the photo above, a series of leads threatens to surround one hut.

But the ANZFLUX trip was more than a quest for solid numbers. It was also an effort to sort out the intricacies of how this unique place works. Before the expedition, for instance, researchers had only a murky sense of how heat from deep ocean water is dissipated at the surface in Antarctica. Needless to say, the researchers' experience sharpened their understanding. But it also created new questions.

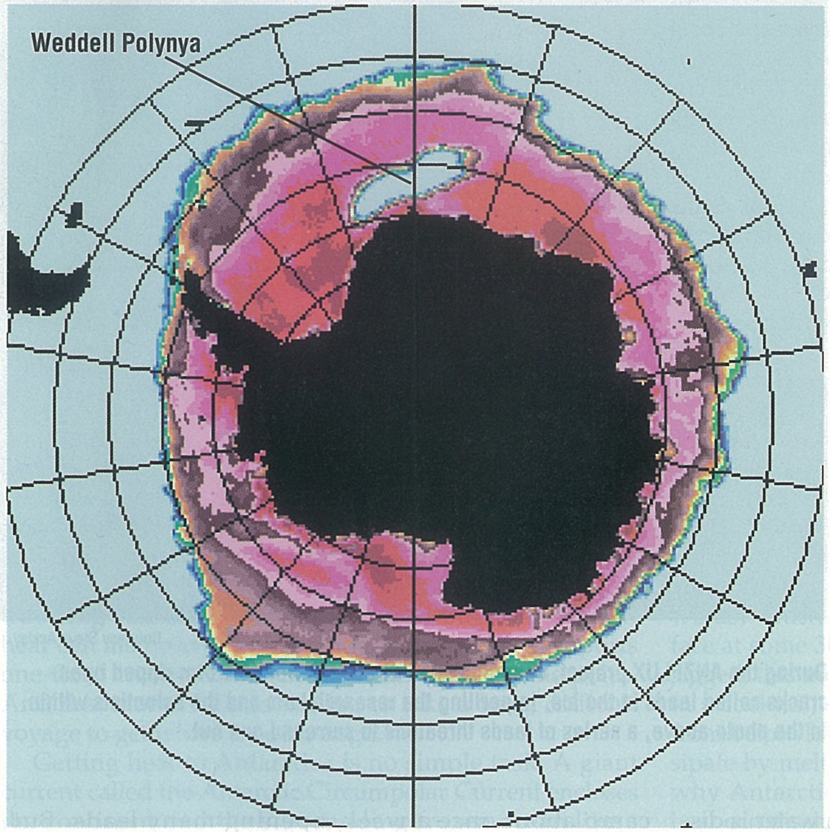
For example, the researchers expected storms to play a major role by opening cracks, or leads, and thereby allowing heat to vent right into the air. Their expectations were met: A storm of near-hurricane strength tore through camp about once a week, opening many leads. But ANZFLUX scientists also discovered that melting of ice may be just as important, says Steve Ackley of the Cold Regions lab. During the project, rising warm water caused extensive melting of the ice from below, thinning it substantially and thereby dissipating considerable heat.

But this raises a problem: If melting of the ice from below is important in dissipating heat from deep ocean



Courtesy Gary Kuehn

ANZFLUX members had to scramble to save themselves and their equipment when cracks opened. The situation was made worse by the winter darkness. Above, a researcher walks over a lead using a sled as a makeshift bridge.



Courtesy NASA Goddard Space Flight Center

In 1974, a hole called a polynya appeared in the winter sea ice surrounding Antarctica. The size of the Black Sea, it persisted until 1976. Scientists don't know why it appeared, and nothing similar has opened since. But they wonder whether new polynyas might open due to global warming. If so, these gaping holes in the winter sea ice could exacerbate the warming by venting large amounts of heat from the relatively warm ocean water near the surface around Antarctica.

water, how does the cover of sea ice survive through winter? A process documented by Ackley may provide the answer. Storms brought snow. With the ice being thinned from below, this weighed the ice down enough to allow water to flood the surface, creating slush. Later, when the storm passed and colder weather returned (storms bring warmer temperatures), the slush froze. Ackley says this process, like the opening and refreezing of leads, appears to be a major way for ocean heat to dissipate while simultaneously maintaining the winter cover of sea ice.

Climate experts must include all these critical interactions in developing computer models to realistically simulate the Antarctic environment. And only with accurate models of current conditions can scientists even begin to predict our climatic future. The big question, of course, is what will happen to the Weddell — and the rest of the world — if rising levels of carbon dioxide from human activities cause average global temperatures to rise? Researchers can't yet say. After all, the exchanges between the ocean, atmosphere and the Antarctic sea ice depend on many other factors that could change if temperatures rise. Until scientists know how such changes would affect the density of the water, for instance, they can't predict how the Antarctic environment might respond. Yet what they know so far suggests that the very volatility of the Weddell might help protect it from change.

Martinson offers a plausible but speculative scenario. Global warming would cause temperatures to rise in the Weddell, which would cause less sea ice to grow. But there would be no runaway shrinking of the winter sea ice cover. With the lower rate of freezing of the ocean surface caused by a warmer atmosphere, less salt would be injected into the surface waters. The surface waters, in turn, wouldn't get as dense and would therefore be less likely to sink and stir up the deep water. This would mean that the deep water, with all its stored heat, would rise to the surface at a slower rate, thereby offsetting the effect of a warmer atmosphere. Eventually there might be somewhat less ice. But thanks to the system's built-in resistance to change, it would reach a steady state.

Ackley also believes the system has built-in stability. But he thinks it arises more from the melting of ice from below and the refreezing of slush from above. If he's right, the stability of sea ice would depend on whether sufficient snowfall, and winds to blow it around, accompany global warming.

Whatever mechanism is more important in maintaining Antarctic sea ice, one thing is clear: The polar Arctic has no built-in stability. Rivers from surrounding lands pour fresh, light water into the Arctic Basin, creating a huge density difference between the surface and deep layers there. Thus, Arctic sea ice is unaffected by the coming and going of heat from below. This makes it a "slave" to the atmosphere, Martinson says. If the air cools, water freezes. No heat from below slows the process. If the air warms, ice melts. And with no venting of heat from the water into the atmosphere, there's no offsetting cooling of the water to slow the melting. In short, the Arctic lacks a self-regulating system. As a result, it might suffer more change from the greenhouse effect than the Antarctic. If global warming began to melt the Arctic sea ice, there might be nothing to put the brakes on.

Courtesy Steve Ackley

Plumes of moisture called sea smoke rise from open water as it gives up its heat to the cold atmosphere. This heat may have been carried here by deep ocean currents from a tropical ocean thousands of miles away. Scientists on the ANZFLUX project discovered that very large amounts of deep ocean heat vent into the atmosphere through openings in the sea ice like the one above, and right through the ice as well.

The possibility of sea ice's melting in the Arctic or Antarctic is of concern because it could actually cause more warming. Even the cold water trapped beneath the ice stores more heat than the frigid polar atmosphere. So, remove the ice and thereby release some of that heat and global temperatures could rise considerably. A model developed at the Goddard Institute of Space Studies in New York, for example, predicts that Earth's global average temperature will rise 4.4 degrees C if levels of carbon dioxide in the atmosphere double. The melting of polar sea ice accounts for an astonishing 38 percent of that warming. But Martinson points out that the Goddard model assumes that Arctic and Antarctic sea ice will behave the same way to warming. In very preliminary modeling of his own, Martinson has found that if one assumes that Antarctic sea ice is more stable than Arctic ice, then global temperatures rise less. "These results tell you how important Antarctic sea ice is in regulating the global climate, at least as projected by a very imperfect atmospheric model," Martinson says.

So at least in the short run, Antarctica's sea ice may cope with global warming, buffering us from change by retaining its delicate stability. But as Martinson cautions, this is indeed a delicate stability. Extreme or sudden climatic shifts could overwhelm its resistance to change.

The Weddell's history supports this point, at least on a local scale. In 1974, satellite images revealed a giant hole in the ice — a lake of melted water as big as the Black Sea. Known as the Weddell Polynya, the hole remains an enigma. By the time icebreakers cracked through the ice in 1981 to investigate, it had disappeared. It's clear, however, that something had fundamentally changed the "setting" of the system, triggering a catastrophic turnover of the water column. Huge amounts of heat were drawn to the surface, essentially burning a hole in the ice.

What would happen if global warming changed the setting in the Weddell on a larger scale? And would any such changes have only regional consequences, or global ones? For now, one thing is certain: Earth would readjust. It has to, Martinson says, because heat will always travel from warm regions to cold ones. The question is whether we would like the consequences of that adjustment.

The day after the storm, the researchers were back on the ice, retrieving the instruments they had left behind. Dramatic climate change was no doubt the last thing on their minds. Even the mundane task of recovering equipment posed real and immediate hazards. Some cracks remained open, but they were hidden under snow. Still, slowly and carefully, the researchers recovered all the equipment and resumed their work again. But they were already satisfied that they had accomplished one of their major goals: measuring the deep ocean heat escaping at the surface in the Antarctic.

It will doubtless take more expeditions before scientists can answer the big questions about the Weddell: how it might adapt to global warming; what might trigger a radical change in the system; whether any such changes would have rippling effects across the globe. But if what scientists know so far proves correct, the resilience of our climate system rests, at least in part, on thin ice. ⊕

Ruth Flanagan is a contributing editor for Earth magazine.