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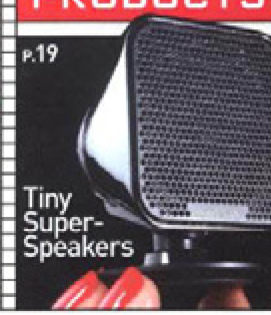
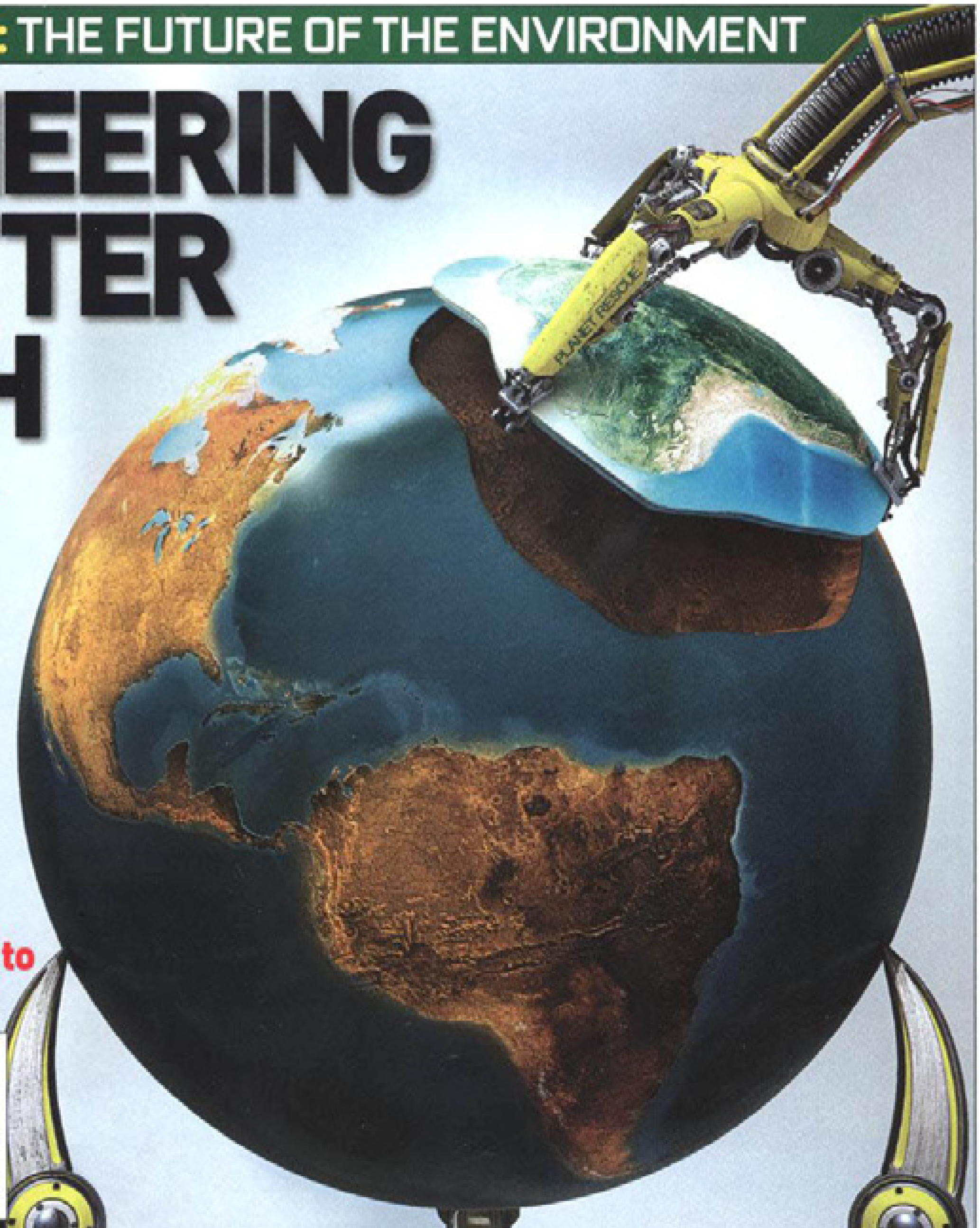

Tiny Super-Speakers

**SPECIAL ISSUE: THE FUTURE OF THE ENVIRONMENT**

# ENGINEERING A BETTER EARTH

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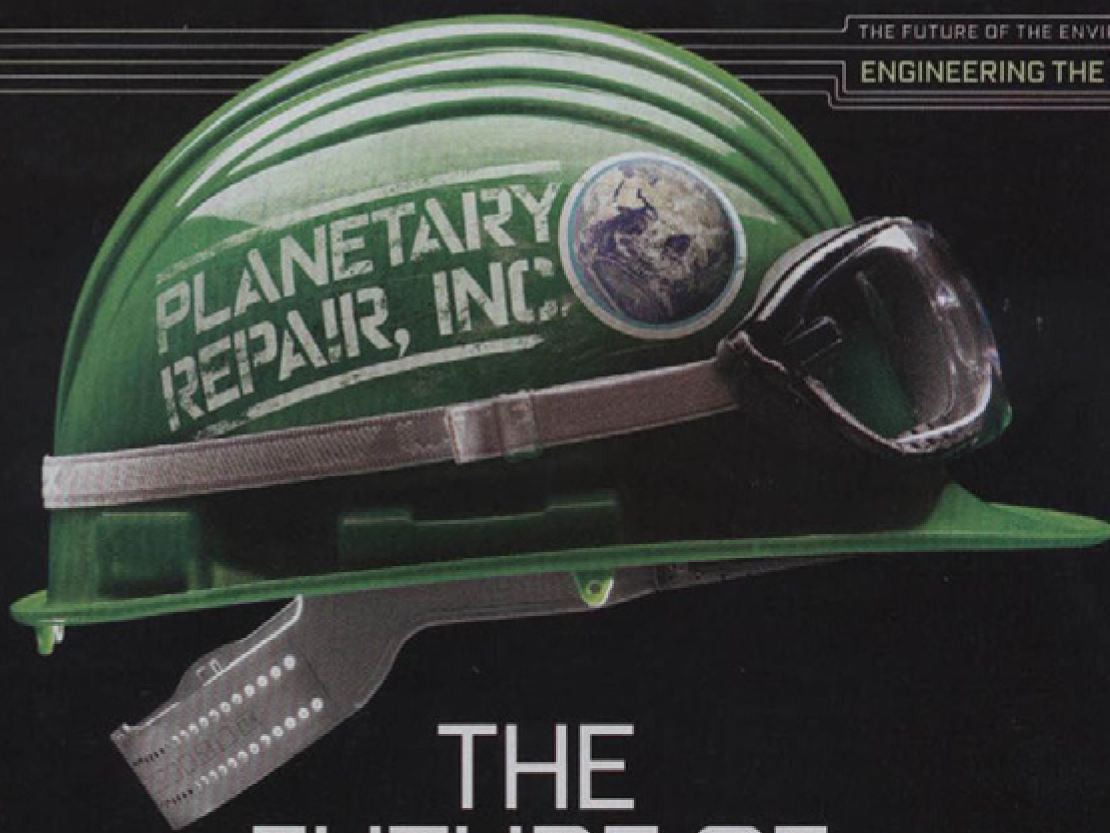



# THE FUTURE OF THE ENVIRONMENT IS NOW

Ignore the hype. Here are the facts. Research at the world's extremes shows that the planet is changing, and the view is even clearer from space. What to do? Adapt. Rethink what's possible. Design new laptops. Make new ice sheets. Change what it means to build a nation. Because whether we like it or not, the future of the environment is upon us. We only have to decide what to do about it.

PHOTOGRAPH: JOHN B. CARNETT; POSTPRODUCTION: NICK KALOTERAKIS

# A REALIST'S GUIDE

## HARD SCIENCE REVEALS WHAT'S REALLY GOING ON

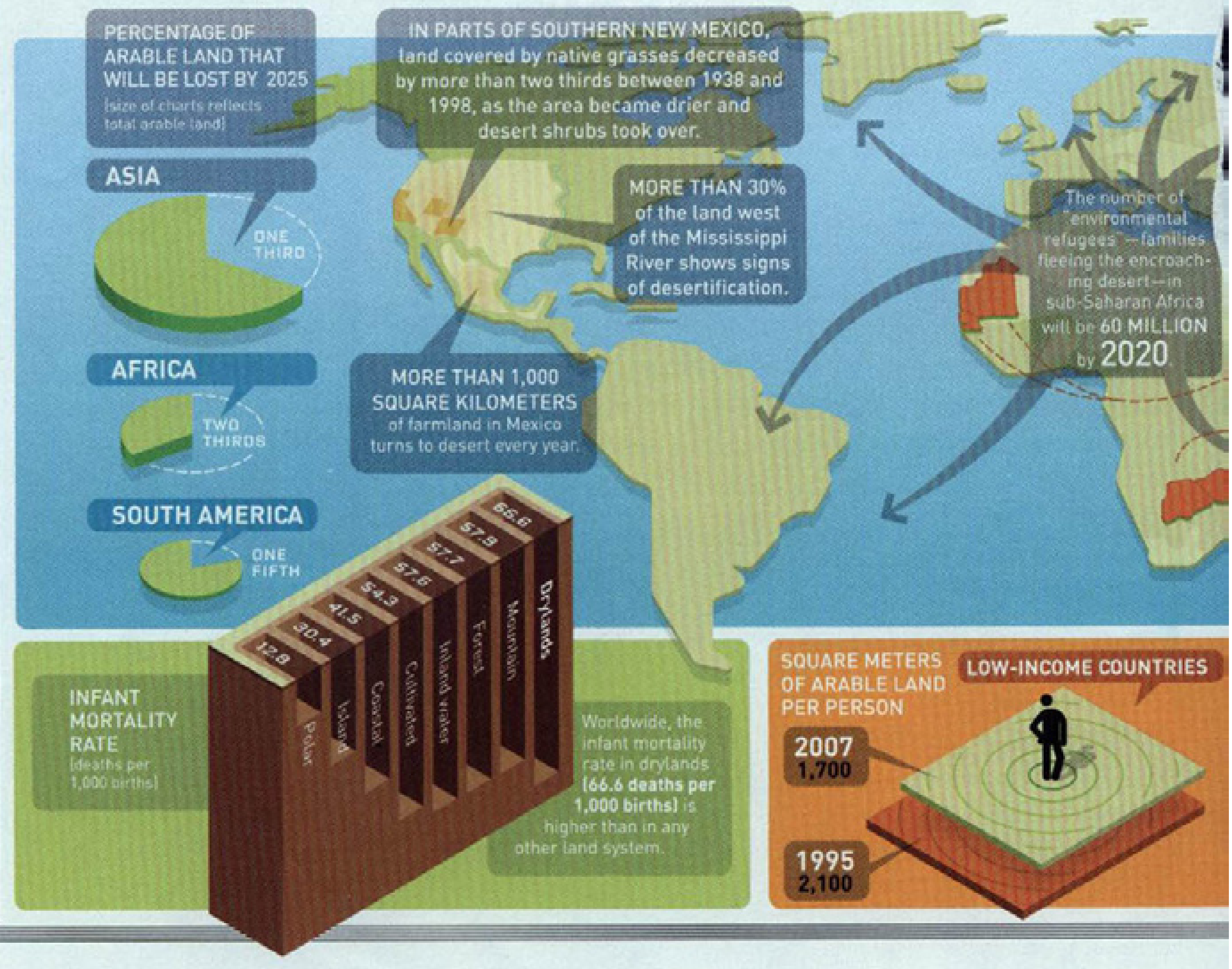
Everyone's heard about climate change, but what is actually happening to the planet? Here are five real environmental challenges that escaped the headlines. Solving them is within the grasp of science—it just takes a little know-how RESEARCH BY KATE PICKERT ILLUSTRATIONS BY XPLANE

## 1. THE WORLD TURNS TO DESERT

**SIMPLY PUT, DESERTIFICATION** is the process of non-desert land becoming desert. It happens when drylands—areas like grasslands and savannas that have low annual rainfall—lose their crucial topsoil-anchoring plants as a result of deforestation or poor agricultural practices, such as overgrazing by farm animals. This leaves the land dry, inhospitable and unable to support food production. Northern Africa and China are most susceptible to desertification, but North America is not immune. If the desertification process isn't curtailed soon, the world stands to lose a significant part of its arable land to barren desert.

Annual cost of desertification:
**$42 BILLION**
Annual cost to combat it*:
**$2.4 BILLION**

* Includes reforestation and agriculture education programs



# TO THE PLANET

**6 MILLION** square kilometers of the Earth's surface are already affected by desertification.

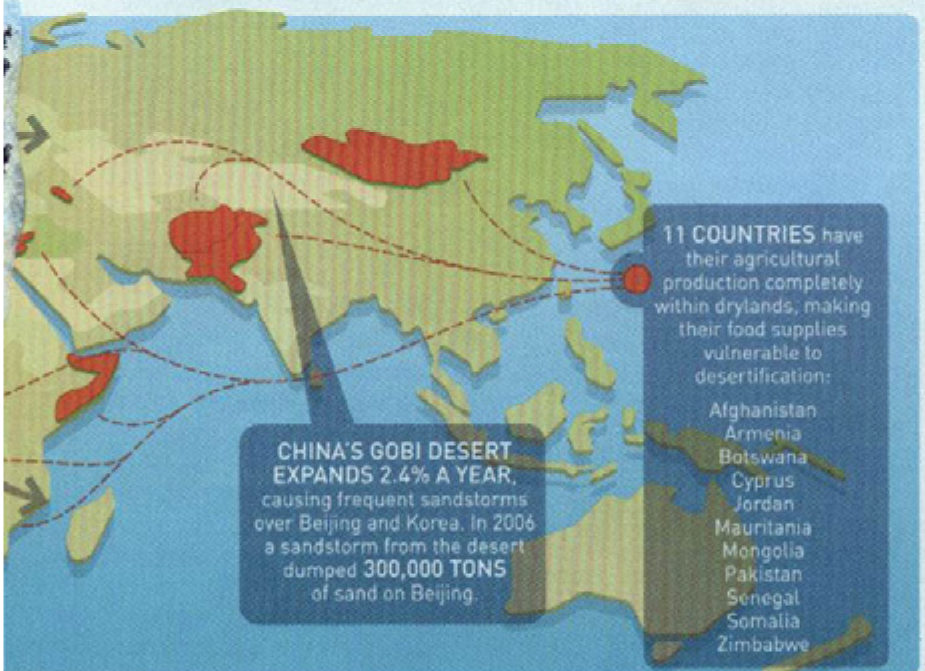
**26%** of the Earth's land surface is classified as severely degraded.

**60,000** square kilometers of productive land are lost to desertification every year.

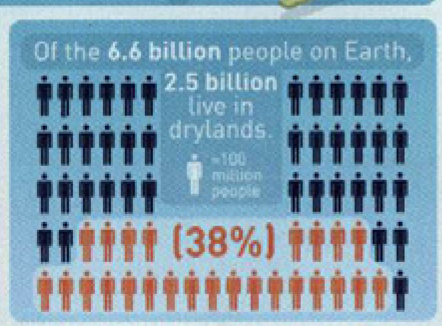
**3,400** square kilometers become desert every year in China, twice the rate of the 1970s.

## THE GOOD NEWS

To help reduce the massive sandstorms that originate in China's deserts every spring, the Chinese government has initiated a program to spend billions of dollars planting trees to form a "green wall" approximately 5,000 kilometers long that may help stop some of the wind erosion of its interior.








## 2. $N_2$ GLUT

**NITROGEN CAUSES** algae to grow uncontrollably, which smothers ecosystems by depriving marine animals of oxygen. The amount of "fixed" nitrogen (the form used by plants and animals) in the environment has dramatically increased as a result of human activity. It contaminates drinking water, causes smog, and upsets marine ecosystems. Below, the effects of nitrogen saturation.

**40%** of the world's population lives on food produced using fixed nitrogen (fertilizer).

**SOURCES OF FIXED NITROGEN:**
**60%** produced by fertilizer
**25%** produced by legumes such as soybeans
**12%** produced by burning fossil fuels

**25%** of excess nitrogen from overfertilization of fields flows into the oceans via rivers.

**100%** of fixed nitrogen produced by burning fossil fuels ends up in soils or waterways.

The amount of fixed nitrogen (mostly agricultural run-off) flowing from the Mississippi River into the Gulf of Mexico is **THREE TIMES AS GREAT** as it was 30 years ago.

**RED TIDE**, a type of harmful algal bloom, is caused in part by excess nitrogen in coastal waters. It produces toxins that can damage the sinuses if inhaled. Red tide also infects shellfish and kills marine animals like manatees and whales.

**60,000 AMERICANS** are poisoned annually by harmful algal blooms, usually after eating contaminated shellfish.

Harmful algal blooms cause at least **$50 MILLION IN DAMAGE** to seafood stocks in the U.S. annually.

Forty years ago, red tide occurred in China about **10 TIMES A YEAR**. Now it occurs approximately **300 TIMES A YEAR**.

**THE GOOD NEWS:** Scientists have developed slow-release fertilizers that allow less nitrogen to leach into the soil.

# 3. MILLIONS DIE OF THIRST

**LESS THAN 1 PERCENT** of all the water on Earth is potable (drinkable) and not locked up in ice. And scientists believe that half of this is already in use. Inefficient irrigation, wasteful household use and a population projected to grow by another three billion all contribute to the planet's growing water shortage. Here's how.

**3,000 LITERS** Amount of water, on average, required to produce enough food for one person per day.

By 2050, up to **2.4 BILLION** people will live in countries where water is scarce.

**1.7 MILLION** people die every year because of poor drinking-water quality, lack of sanitation and poor hygiene related to water shortages.

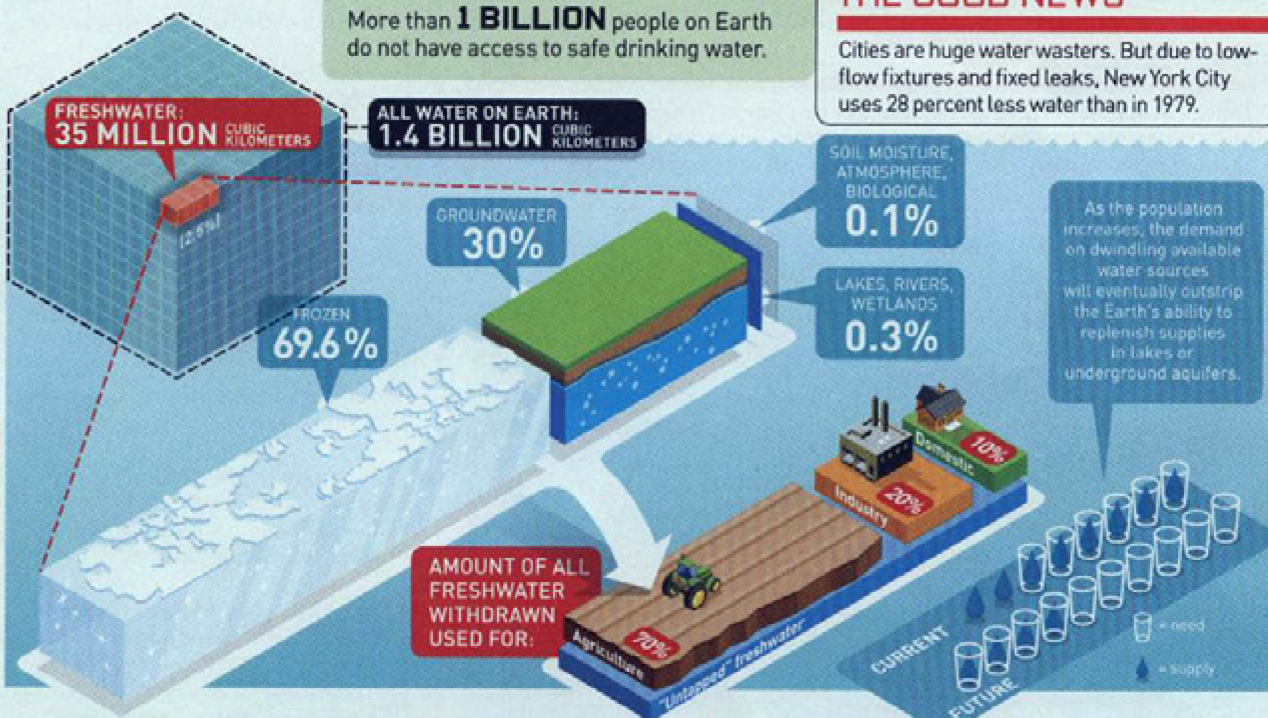
More than **1 BILLION** people on Earth do not have access to safe drinking water.

Residential daily water use, per capita:
**350 LITERS** in North America and Japan
**200 LITERS** in Europe
**10–20 LITERS** in sub-Saharan Africa

**50%+** of the U.S. population is dependent on groundwater. In Arizona the water table drops by one meter per year.

## THE GOOD NEWS

Cities are huge water wasters. But due to low-flow fixtures and fixed leaks, New York City uses 28 percent less water than in 1979.




# 4. MURKY ARCTIC HAZE

**THE ARCTIC IS NOT AS PRISTINE** as it once was. Pollution from industry and forest fires concentrates during the winter months above the Arctic Circle, producing an orange-brown haze that is visible from the ground during early spring. This pollution, mostly sulfur and nitrogen compounds, traps heat, contributing to the melting of Arctic ice, and when the pollution falls to the ground during spring rainstorms, it flows directly into our oceans.

The Arctic is **TWO TO THREE DEGREES WARMER** during the winter seasonal arctic haze than it would be if the air was not polluted.

Pilots flying in Arctic-haze clouds report that **VISIBILITY IS ABOUT ONE TENTH** of what it is during clear skies.

The Arctic is **10 TO 20 TIMES AS POLLUTED** as Antarctica because Antarctica is so much more remote.

The **HIGHEST CONCENTRATIONS** of pollutants are found within two kilometers of the Earth's surface but extend as high as eight kilometers.

At a monitoring station in Alert, Alaska, the concentration of nitrates in the atmosphere **INCREASED 67%** between 1981 and 2000.

Atmospheric sulfate levels can be up to **25 TIMES AS HIGH** in the haze season as at other times of the year.

**THE GOOD NEWS:** Sulfur dioxide emissions in Europe, which contribute to Arctic haze, were reduced 67% between 1980 and 2000, when more efficient sulfur scrubbers were installed in smokestacks and coal mines were shut down.

**SOURCES:** Peter H. Gleick, *The World's Water*, The Pacific Institute; World Resources Institute; U.N. System-Wide Earthwatch; U.N. World Water Development Report 2; World Water Council; Organization for Economic Cooperation and Development, International Futures Programme; World Wildlife Fund; Unesco; Global Coral Reef Monitoring Network Report, 2004; Millennium Ecosystem Assessment; *Reefs at Risk*, World Resources Institute; International Center for Living Aquatic Resources Management; World Conservation Monitoring Center; U.N. Environment Programme, 1998; Arctic Monitoring and Assessment Programme; Ecological Society of America; World Bank; U.N. Food and Agriculture Organization; U.K. *Daily Telegraph*; Earth Policy Institute; U.N. Convention to Combat Desertification; U.N. Economic Commission for Europe; "The Nitrogen Cascade," *BioScience*; American Meteorological Society; North South Basin Summit, 2003; China Policy Institute; Woods Hole Oceanographic Institute; *Los Angeles Times*

# 5. CORAL-REEF RETREAT

**CORAL REEFS PLAY** a central role in the marine ecosystem, are a valuable source of potential pharmaceutical compounds, and provide habitat to a full quarter of the ocean's species. But marine pollution, overfishing, coral bleaching and scuba-diving tourists are threatening half the world's coral reefs with extinction.

**ABOUT ONE THIRD** of fish inhabiting coral reefs worldwide are labeled "critically endangered." Some reefs have **FEW FISH BIGGER THAN 10 CENTIMETERS** long because of overfishing.

**0.2%** of the ocean floor holds coral reefs, yet those reefs are home to more than one million (25%) marine species, including 4,000 types of fish.

**58%** of coral reefs are located within 50 kilometers of major urban centers.

## THE GOOD NEWS

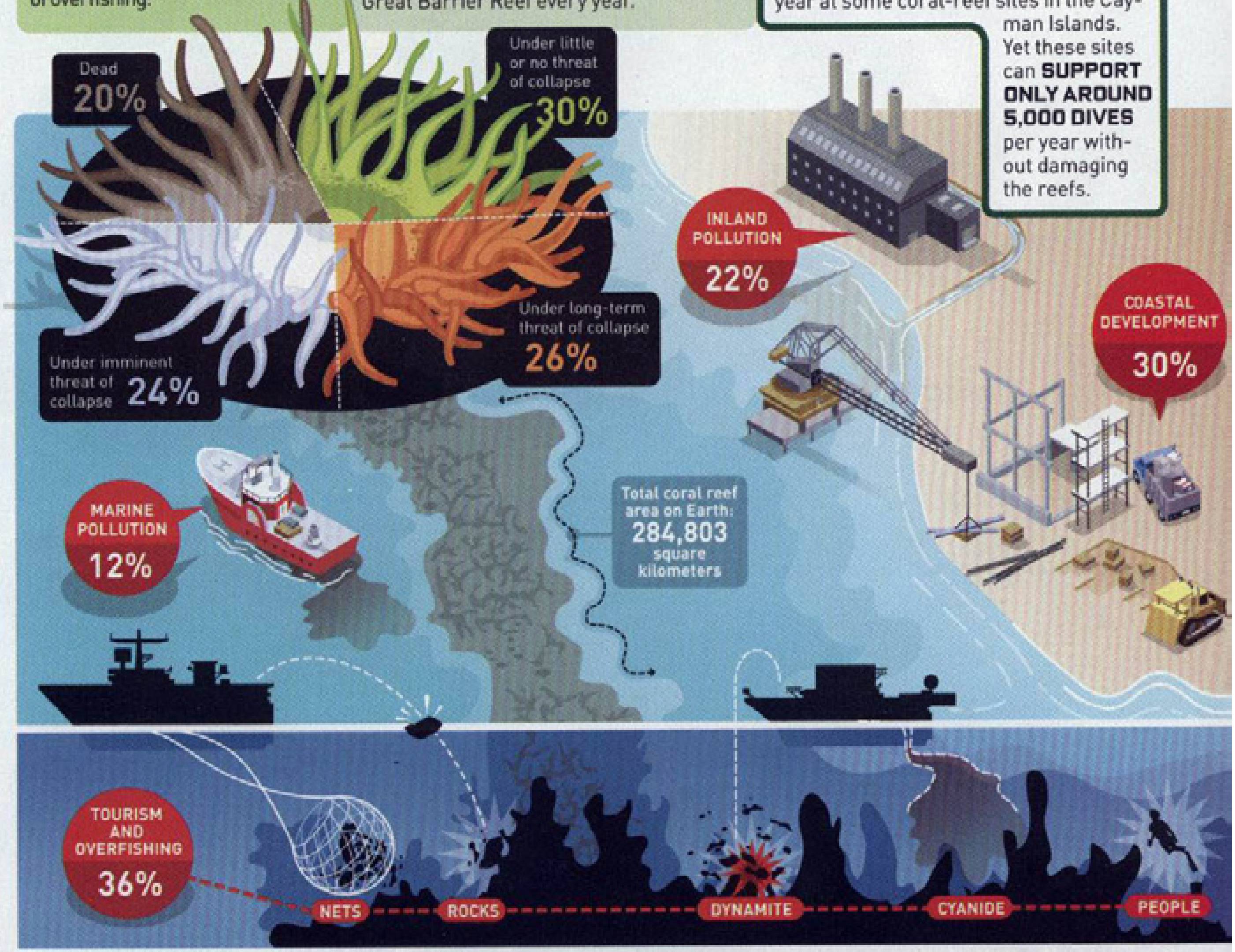
In 1998, 16 percent of the world's coral reefs were killed by bleaching caused by El Niño, but half of those reefs are showing signs of recovery, especially in protected areas, in places where it is illegal to harvest coral, and far from coasts.

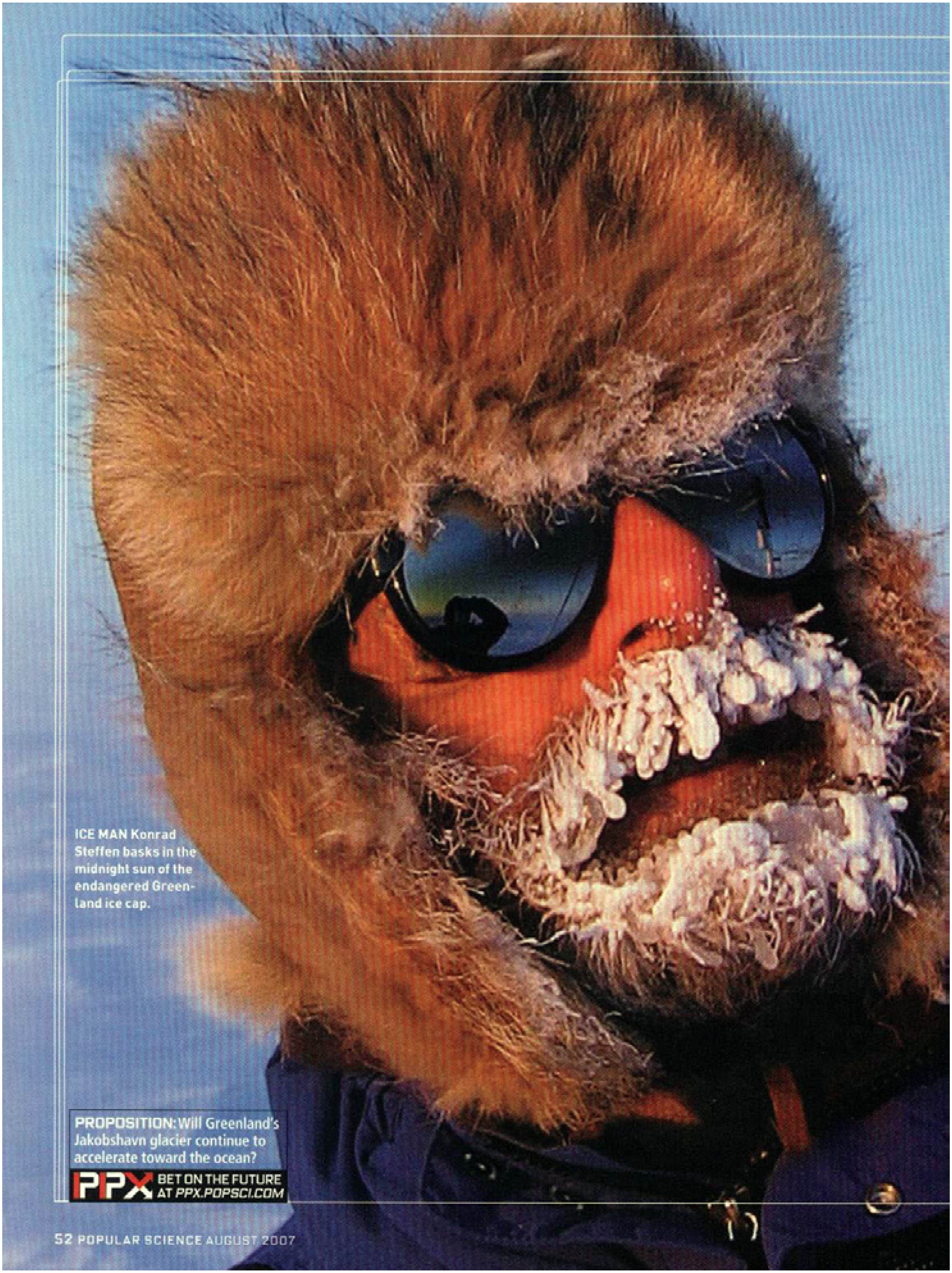
**1.5 MILLION+** people visit the Great Barrier Reef every year.

**SPONGES** found on a coral reef in the Caribbean were used to develop the HIV-fighting drugs Ara-A and AZT and the cancer-fighting drug Ara-C.

Coral reefs generate **$30 BILLION** in revenue every year worldwide from tourism, fishing and other sources. If reefs are degraded at current rates, by 2015, the Caribbean alone will lose at least $350 million per year.

**15,000** dives are performed every year at some coral-reef sites in the Cayman Islands. Yet these sites can **SUPPORT ONLY AROUND 5,000 DIVES** per year without damaging the reefs.





ICE MAN Konrad Steffen basks in the midnight sun of the endangered Greenland ice cap.

# THE PROPHET OF MELT

**Arctic climatologist Konrad Steffen has spent 18 consecutive springs on the Greenland ice cap, personally building and installing the weather stations that help the world's scientists understand what's happening up there. And what's happening may be much worse than anyone thought possible** BY TOM CLYNES

**IN 1990, WHEN CLIMATOLOGIST** Konrad Steffen established Swiss Camp, one of the first automatic weather stations on Greenland's ice sheet, global warming wasn't high on his agenda. Steffen wanted to study the interaction of ice and atmosphere at the "equilibrium line," the altitude where summer melt and winter snowfall are historically in perfect balance. "We probably have more information on nearby planets than we do on Greenland," he says. "Parts of Greenland have never been measured, because few satellites can see that latitude, and those that can haven't been up long enough. And it's difficult to deploy surface instruments in those conditions." Steffen's aim was to begin filling in gaps in scientists' understanding of the processes that drive—and are affected by—changes on the vast body of ice that holds roughly 8 percent of the world's freshwater supply.

But near the Earth's poles, equilibrium isn't what it used to be. A few years after Steffen built his research station, he noticed that temperatures on Greenland's ice cap were rising—and then rising faster. Over a decade, the average winter temperature shot up 7°F, an increase so improbable that at first Steffen declined to publish it, fearing an error in his calculations.

Then again, he didn't need to double-check his data to see that the ice cap was changing. Swiss Camp's weather towers, which hold solar-powered monitoring equipment atop bases set 13 feet deep in the ice, began toppling over. In 1997 Steffen flew over Jakobshavn glacier in west Greenland and was shocked to see that its tongue had collapsed, "as if somebody had hit it with a massive hammer." A speed check showed that Jakobshavn, already the world's fastest-moving glacier, was accelerating; its velocity would double between 1997 and 2003.

A glacier that accelerates with a warming atmosphere is within the realm of scientific expectation. But according to the conventional wisdom of glaciology, the massive ice sheets that cover most of Greenland and Antarctica should

## THREE KEY FACTS

1. **Greenland is an indicator of things to come in the rest of the world** because of its sensitivity to climate changes and because its ice sheet exerts a tremendous influence on many of the Northern Hemisphere's ecological cycles.
2. **Over a recent 10-year period, the average winter temperature on the ice cap shot up by 7°F,** a surge so huge that at first Konrad Steffen feared he had miscalculated.
3. Steffen's data suggests that **sea levels may rise by as much as three feet by 2100**—higher and faster than even the most pessimistic forecasts predicted.

respond much more slowly to variations in temperature, with appreciable changes happening across hundreds and thousands of years. Yet Steffen's ground-based instruments and satellite data were showing that the ice under Swiss Camp was accelerating as temperatures rose, flowing at speeds of up to 20 inches a day as ice melted in places where it had once stood solid. Seismographs picked up increasingly frequent ice quakes, as the 5,000-foot-thick ice cap lurched toward the sea. By 2006, Greenland's ice sheet was shedding some 150 gigatons per year—a mass surpassing all the ice in the Alps. "We realized that something was going wrong," Steffen says. "Greenland was coming apart."

**MOULIN BLEU** Steffen [right] prepares to explore a moulin, a fissure that drains meltwater to the bedrock.

## CANARY ON THE ICE CAP

In the annals of polar science, Konrad Steffen will go down as one of the legends. Koni, as he is known by his friends and colleagues, oversees an annual budget of $50 million and a staff of 550 at the Cooperative Institute for Research in Environmental Sciences (CIRES) in Boulder, Colorado, a research center that is jointly funded by the National Oceanic and Atmospheric Administration and agencies like NASA. But Steffen has had the most influence not as an administrator but as an icy-boots explorer. He has spent the past 32 summers in the high Arctic, working in Alaska and Canada before settling on Greenland, where his Greenland Climate Network serves as the eyes and ears for climate scientists worldwide. In this extreme environment, the on-the-ground reality was invisible until Steffen personally customized and deployed much of the instrumentation that tells the scientific world, hour by hour and year by year, the conditions on the Greenland ice sheet and how they're changing.

## "WE REALIZED," STEFFEN SAYS, "THAT GREENLAND WAS COMING APART."

The news isn't heartening. In fact, new data that Steffen and his colleagues are just beginning to truly understand suggest that the seemingly dire warnings in the recent reports from the U.N.'s Intergovernmental Panel on Climate Change (IPCC) may turn out to be profoundly understated.

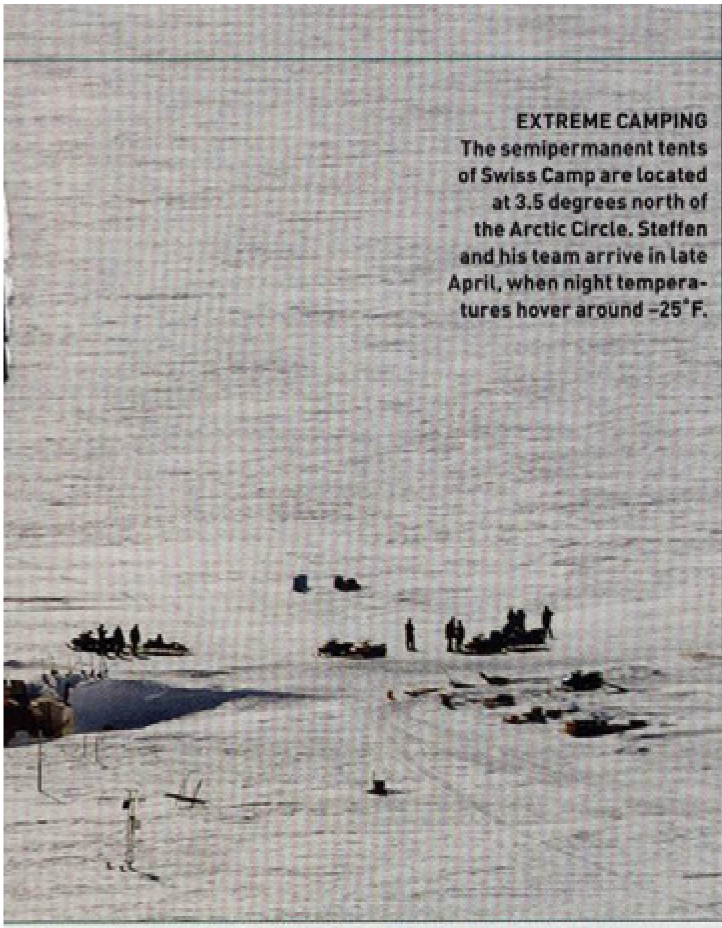
Climatologists have found that the best places to study global warming are the coldest regions on Earth. The Arctic, the Antarctic and the world's highest mountains respond to temperature changes more rapidly and dramatically than anywhere else on the planet. Greenland, especially, has become a kind of barometer for the rest of the world because of its sensitivity to climate changes and because its ice sheet—which Steffen calls "the weather machine of Europe"—exerts a tremendous influence on many of the Northern Hemisphere's ecological cycles. Meltwater from the Greenland ice sheet is the largest potential contributor to sea-level rise, so what happens in Greenland over the next decade will answer key questions about how the rest of the Earth will fare in the next century.

This year, researchers from some 60 nations are participating in the International Polar Year, an intensive burst of interdisciplinary research focusing on the polar regions. Thus far, the data the researchers have seen—much of which was harvested from Steffen's Greenland Climate Network—has been alarming. Water from the melting ice sheet is gushing into the North Atlantic much faster than scientists had previously thought possible. The upshot of the news out of Swiss Camp is that sea levels may rise much higher and much sooner than even the most pessimistic climate forecasts predicted.

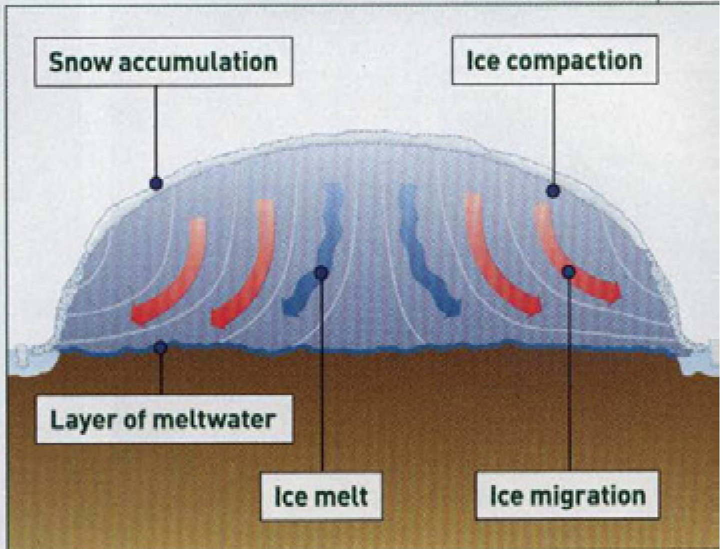
## THE PILGRIMAGE TO SWISS CAMP

Koni Steffen doesn't look like a worried man when I catch up with him on a mid-April afternoon at the airport in Albany, New York, the layover in his annual pilgrimage from Boulder to Greenland. Steffen is tall and wiry, with stringy brown hair and a graying beard. He has intense, grayish-blue eyes and the furrowed, leathery cheeks you might expect of a man who has spent more than half of his 55 summers squinting into a

PHOTOGRAPH: BOB STRONG/REUTERS; INSET: COURTESY KONRAD STEFFEN; PRECEDING PAGES: JASON BOX; FACING PAGE: STEVE CROSS



**EXTREME CAMPING** The semipermanent tents of Swiss Camp are located at 3.5 degrees north of the Arctic Circle. Steffen and his team arrive in late April, when night temperatures hover around -25°F.




## ICE-SHEET ANATOMY

**THE SPRAWLING** ice sheet covering the world's largest island provides habitat for many arctic species and holds nearly 8 percent of the world's freshwater—enough to raise global sea levels by 21 feet. It is, on average, 5,000 feet thick and is constantly being replenished as snow falls each winter. Over the course of centuries, the snow compacts into ice, which slides toward the ocean. In recent years, higher atmospheric concentrations of heat-trapping gasses have accelerated that process. As temperatures rise, the top layers melt, giving way to darker, heat-absorbing ice and liquid water. The meltwater seeps down to the rock below, lubricating the ice mass and speeding its trip to the sea.

bitter wind. In his speech, I can hear the lilting inflections of Schweizterdeutsch (Swiss German), the "secret language" he speaks at home with his wife and two children.

The three duffels Steffen tosses into my Jeep don't hint at the 82 cargo boxes he has shipped ahead, after two all-night packing binges. The next morning—at 4:30 a.m., to be precise—Steffen, his crates and his three graduate students will board a C-130 at the Air National Guard base in Schenectady. The plane, which is outfitted with retractable skis, will make a long, slow flight to Kangerlussuaq, on Greenland's west coast.

From there, Steffen and his team will board a ski-fitted Twin Otter to southern Greenland, where they will be left alone on the ice sheet. Working through the nights and sleeping "only when necessary" to get everything done before bad weather socks them in, they will spend the next three days leapfrogging northward from one location to the next, repairing equipment and setting up new weather stations. "And then," Steffen says, his eyes lighting up, "we'll arrive at Swiss Camp."

Swiss Camp, located 3.5 degrees north of the Arctic Circle, is a collection of three semipermanent tents and a vestibule that doubles as a sauna. Steffen and his team typically arrive at the camp in late April, when night temperatures hover at around -25°F. A day's (or night's) work might include chiseling gear and work space out of solid ice, coaxing frozen equipment back to life, or hiking 10 miles back to camp from a broken-down snowmobile. "I have to make sure my grad students are very fit," Steffen says.

Shortly after arrival at Swiss Camp, Steffen often sets out alone on his snowmobile—packing a sleeping bag, a pack of Marlboros and a satellite phone—to scout a path through the ever-changing landscape of cliffs, meltwater lakes and deep crevasses that lie between the camp and the weather station. The station, 10 miles away, is set in a jumbled ice field stuck with poles holding aloft monitoring equipment that ranges from basic weather instruments to radio spectrometers, GPS units and seismographs.

"I remember when I first arrived at Swiss Camp," says Waleed Abdalati, a former graduate student who now directs the Cryospheric Sciences Branch of the NASA Goddard Space Flight Center. "I was thinking, What are the odds of this stuff making it through even one winter? And now, 18 years since he first set it up, if you made a list of the scientists who have used those data sets, it would be huge. Without Koni, the body of knowledge about Arctic climate, warming and melting dynamics would be severely limited."

### MARLBORO (AND ESPRESSO) MAN

Steffen's contemporaries marvel at his ability to attract talent and long-term funding to his research projects—and at his capacity for work. At CIRES, Steffen supervises several ongoing field projects funded by NASA and the National

**SMOOTH OPERATOR** Steffen with his sled-mounted radar system, which detects melt channels inside the ice sheet.

**ARCTIC MacGYVER** In operation since 1990, this weather station is one of 25 linked by satellite to Steffen's lab in Colorado. He maintains them himself.

Science Foundation. As a University of Colorado professor, he mentors a handful of graduate students while also teaching graduate-level classes and working on his own research. He has authored or co-authored more than 50 peer-reviewed scientific papers, and he is one of the few scientists who advises both Al Gore and the Bush administration.

"He only sleeps three or four hours a night," says Jason Box, a former Steffen protégé now at Ohio State University's Byrd Polar Research Center. "There has been some speculation among us that he isn't actually human. Some of his students believe that he has espresso running through his veins."

Indeed, a strong cup of coffee is the first thing on Steffen's agenda in Schenectady. We park downtown and walk toward a café in a cobbled courtyard, stopping outside to allow him a quick cigarette. "I quit once," Steffen says, "for 24 hours, in 1978."

**STEFFEN CALLS THE ICE SHEET "THE WEATHER MACHINE OF EUROPE."**

As he smokes, he tells me how. In the late 1970s, Steffen spent two winters on an ice floe in Lancaster Sound, near Baffin Island, collecting data for his doctoral dissertation. While traversing a glacial slope, he set off an avalanche and was knocked from his snowmobile. He woke up some time later in a blizzard, with a dislocated jaw and a bone protruding from his lower leg.

"I couldn't get the Ski-Doo started," he says, "and my leg was hanging loose. I dragged myself to a place where we had put an aluminum stake to mark a measuring point. I pulled out the stake and used it to straighten my leg. Then I pushed the snowmobile on its side to get some shelter. I had to get up on my good leg every half hour to jump around, to keep the circulation going. Smoking was out of the question, because I knew that if you smoke, you open your blood vessels; I would freeze to death."

When the storm died down, eight hours later, his research partner, Karl Schroff, began searching for him on foot. (Their other snowmobile had broken through the sea ice and sunk a few days earlier, dunking Steffen in 30°F water.)

"Karl was on the top of the ice sheet," Steffen recalls, "and he could hear something like *krrrack, krrrack*. He knew this kind of a bird did not exist there, so he followed the sound. It was me yelling his name, with no voice left."

Schroff left Steffen with a piece of chocolate and went back to their camp to radio for help. After no one replied to his first round of mayday calls, he fell asleep from exhaustion. A few hours later, he woke and tried again. This time he reached a U.S. Air Force plane, flying toward Thule AFB. A Canadian rescue party eventually plucked Steffen off the ice, 24 hours after he was knocked off his snowmobile. In his pocket was a farewell letter to his then girlfriend, now his wife. "I still have it," he says. "I never gave it to her."

"Anyway," Steffen says, stubbing out his cigarette, "it was good to know that I could quit if I really needed to."

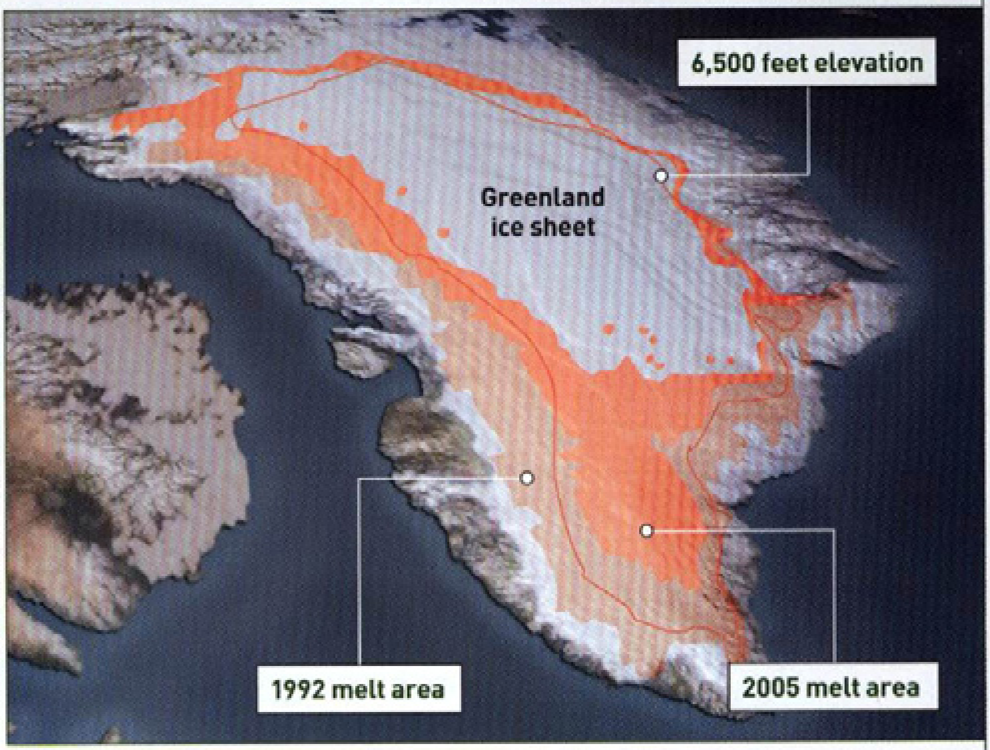
## THE SECRET LIFE OF ICE SHEETS

For the past 14 years, NASA glaciologist Jay Zwally has been Steffen's regular partner on the Greenland ice cap. When they were young scientists, conventional wisdom held that ice sheets, unlike glaciers, respond extremely slowly to

PHOTOGRAPHS, FROM LEFT: COURTESY RUSS HUFF; BOB STRONG/REUTERS; FACING PAGE: PAUL WOOTTON

## DWINDLING SNOW CONE

**KONRAD STEFFEN'S** work has shown that the extent of snowmelt in Greenland increased drastically between 1992 and 2005. Some frozen areas of Greenland have always melted each summer, but as global temperatures rise, Steffen's instruments have detected melting at higher elevations and latitudes. Instead of liquefying merely around the southern and eastern edges of Greenland, the ice pack is melting farther north and farther inland than before. Some scientists believe that large amounts of Greenland's melted freshwater could dilute the salinated water of the Gulf Stream, disrupting the movement of the North Atlantic waters that regulate weather in Europe.




warming, losing substantial mass only over hundreds of years as meltwater runs off the top or evaporates. But as Zwally and Steffen looked at their data trends, they suspected that another process must be at work. "This is not just melting," Steffen says. "You cannot melt this much ice this quickly."

They theorized that meltwater on the surface of the ice cap was draining through fissures down to the bedrock nearly 4,000 feet below. To test the theory, they installed a network of GPS transceivers, accurate to a few centimeters. They compared the GPS measurements with data from satellites, ground-penetrating radar and other instruments. Then, in a 2002 paper that jolted the scientific community, they concluded that ice-sheet flow accelerates with surface melting, similar to glaciers.

"We call this phenomenon 'dynamic response,' " Steffen says. "What happens is that the melting accelerates as meltwater funnels down to the bedrock. At the bottom, the water acts as a lubricant, flowing under the outlet glaciers and allowing the ice to slip into the sea more quickly. We hadn't expected that ice sheets could react to warming so quickly. But that is the kind of feedback we are coming to understand in the Arctic; it's a very sensitive environment."

The current acceleration could be a short-term adjustment to the warmer temperatures, Steffen says, or it might last much longer. But some scientists, including lead NASA climatologist James Hansen, believe that Zwally and Steffen's observations, coupled with new data from Antarctica, suggest that a major polar melt may be commencing. They point to a phenomenon called the albedo effect, in which melting ice exposes more land and water, causing the earth's surface to become less reflective, and to absorb more of the sun's energy.

In a 2005 article in the scientific journal *Climate Change*, Hansen wrote that the current pace of melting, driven by the buildup of greenhouse gases in the atmosphere, could lead to a self-reinforcing and perhaps unstoppable cycle of feedback that could result in the total disintegration of the Greenland ice sheet. Hansen and many other climatologists believe that it is likely that the ice sheet will begin melting uncontrollably if global temperatures climb more than 3.6°F. A rapid meltdown in Greenland would quickly raise sea levels around the world and flood coastal cities and farms. As well as sending large icebergs down the coast, the infusion of cold, fresh water could disrupt ocean currents such as the Gulf Stream, which help to keep the weather in the Northern Hemisphere regulated. "If that feedback kicks in," says Steffen, "then the average person will worry."

But because dynamic response is so poorly understood, it has not yet been incorporated into the numerical models that climatologists use to project sea-level changes. For this reason, the potential influence of dynamic response on sea-level rise wasn't factored into the sea-level projections in the "Climate Change 2007" report that the IPCC released earlier this year.

A consensus of hundreds of scientists from 130 countries, the IPCC report concludes that the warming of the climate "is unequivocal," as evidenced by rising temperatures, widespread melting of snow and ice, and rising sea levels. The report, essentially a meta-analysis of 70 climate-modeling studies, predicts a long, slow [CONTINUED ON PAGE 102]

# ENDANGERED

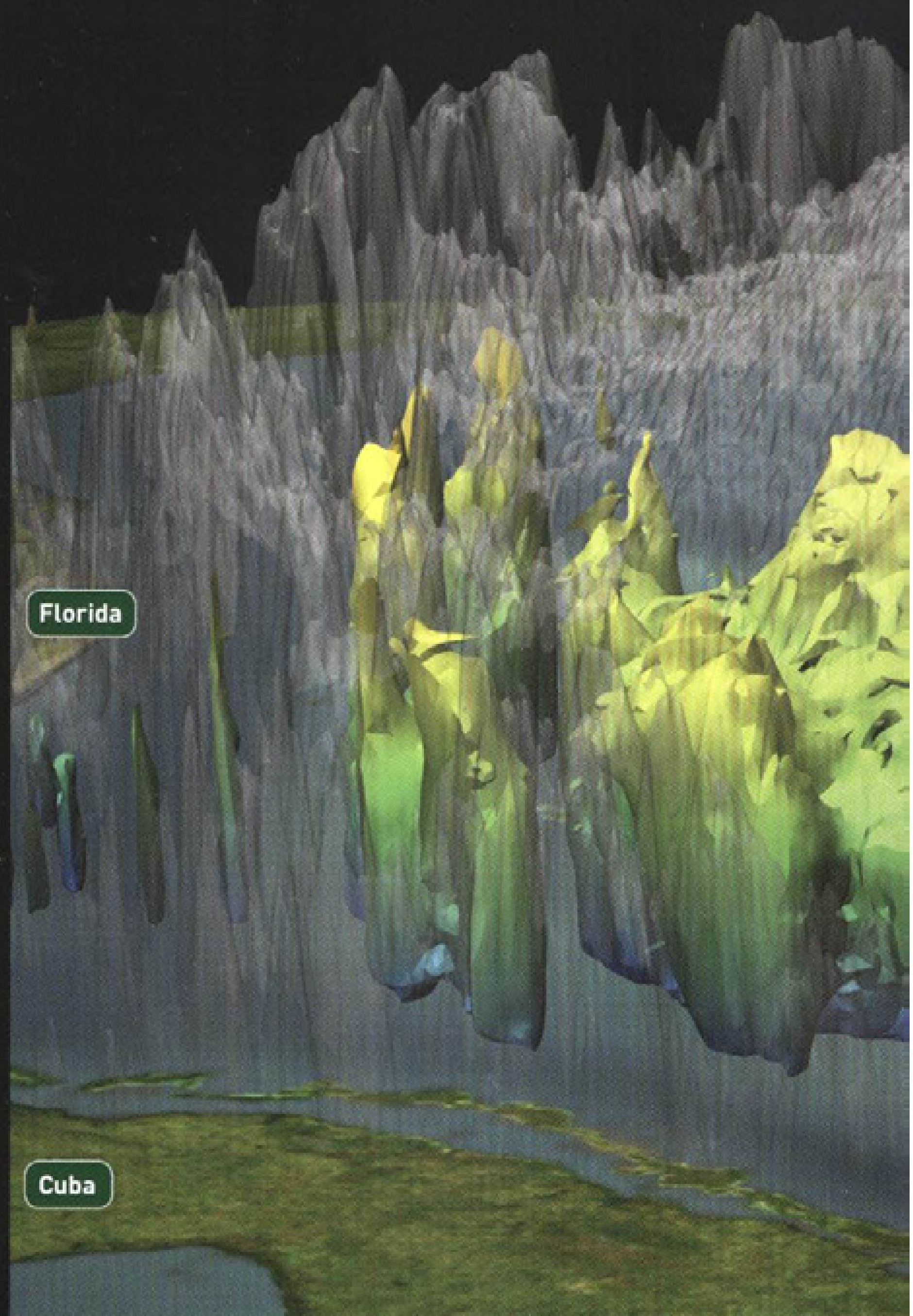
**THE NATION'S SATELLITES DOCUMENT ENVIRONMENTAL THREATS AROUND THE GLOBE. SO WHY IS THE FUTURE OF EARTH OBSERVATION IN PERIL? BY LAURA ALLEN**

The American Association for the Advancement of Science calls it a crisis. Atmospheric scientist Timothy L. Killeen, the president of the American Geophysical Union, says it "could harm our ability to protect our citizens." We call it plain old scary. It's the endangered future of our nation's arsenal of Earth-observing satellites, the 42 instruments that enable scientists to monitor the planet. Satellite images and colorful data sets like the ones on the following pages help researchers track killer hurricanes, plan conservation efforts, manage water resources, and predict glacial melting.

Yet our fleet is aging, and badly. A recent National Research Council report predicts that by 2010, the number of working satellite sensors will drop by 40 percent. Even more troubling, it warns that the next generation of sensors won't be able to adequately address the ever more intricate questions that scientists will pose about the land, sky and oceans over the next decade.

Blame in part the shifting priorities of NASA, one of the main agencies that manage our satellites. NASA's earth-science budget decreased 30 percent between 2000 and 2006. Although the space agency has requested a $1.1-billion increase over 2007, most of its budget is going to fund the International Space Station and President Bush's Vision for Space Exploration, a plan to send humans back to the moon by 2020 and, ultimately, to Mars.

We support sending humans to space, but let's not forget where we live *now.* The U.S. needs a timely recommitment to Earth observation. Otherwise, our ability to monitor, predict, and respond to dire environmental threats will continue to erode.




NASA/GODDARD SPACE FLIGHT CENTER SCIENTIFIC VISUALIZATION STUDIO

# ORBITS

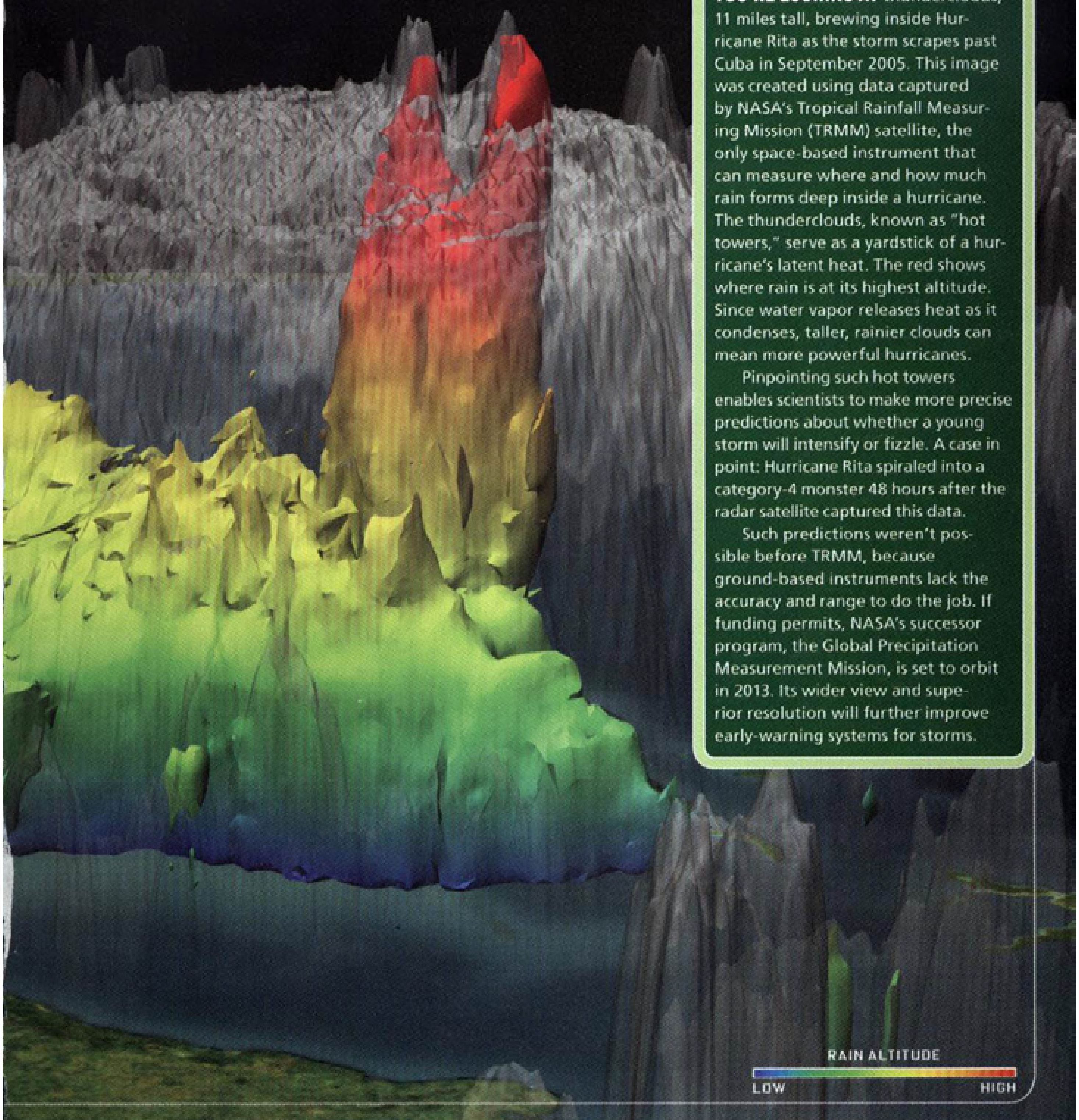
## RED HOT CLOUDS

Scientists scrutinize "hot towers" to predict nightmare storms

**YOU'RE LOOKING AT** thunderclouds, 11 miles tall, brewing inside Hurricane Rita as the storm scrapes past Cuba in September 2005. This image was created using data captured by NASA's Tropical Rainfall Measuring Mission (TRMM) satellite, the only space-based instrument that can measure where and how much rain forms deep inside a hurricane. The thunderclouds, known as "hot towers," serve as a yardstick of a hurricane's latent heat. The red shows where rain is at its highest altitude. Since water vapor releases heat as it condenses, taller, rainier clouds can mean more powerful hurricanes.

Pinpointing such hot towers enables scientists to make more precise predictions about whether a young storm will intensify or fizzle. A case in point: Hurricane Rita spiraled into a category-4 monster 48 hours after the radar satellite captured this data.

Such predictions weren't possible before TRMM, because ground-based instruments lack the accuracy and range to do the job. If funding permits, NASA's successor program, the Global Precipitation Measurement Mission, is set to orbit in 2013. Its wider view and superior resolution will further improve early-warning systems for storms.

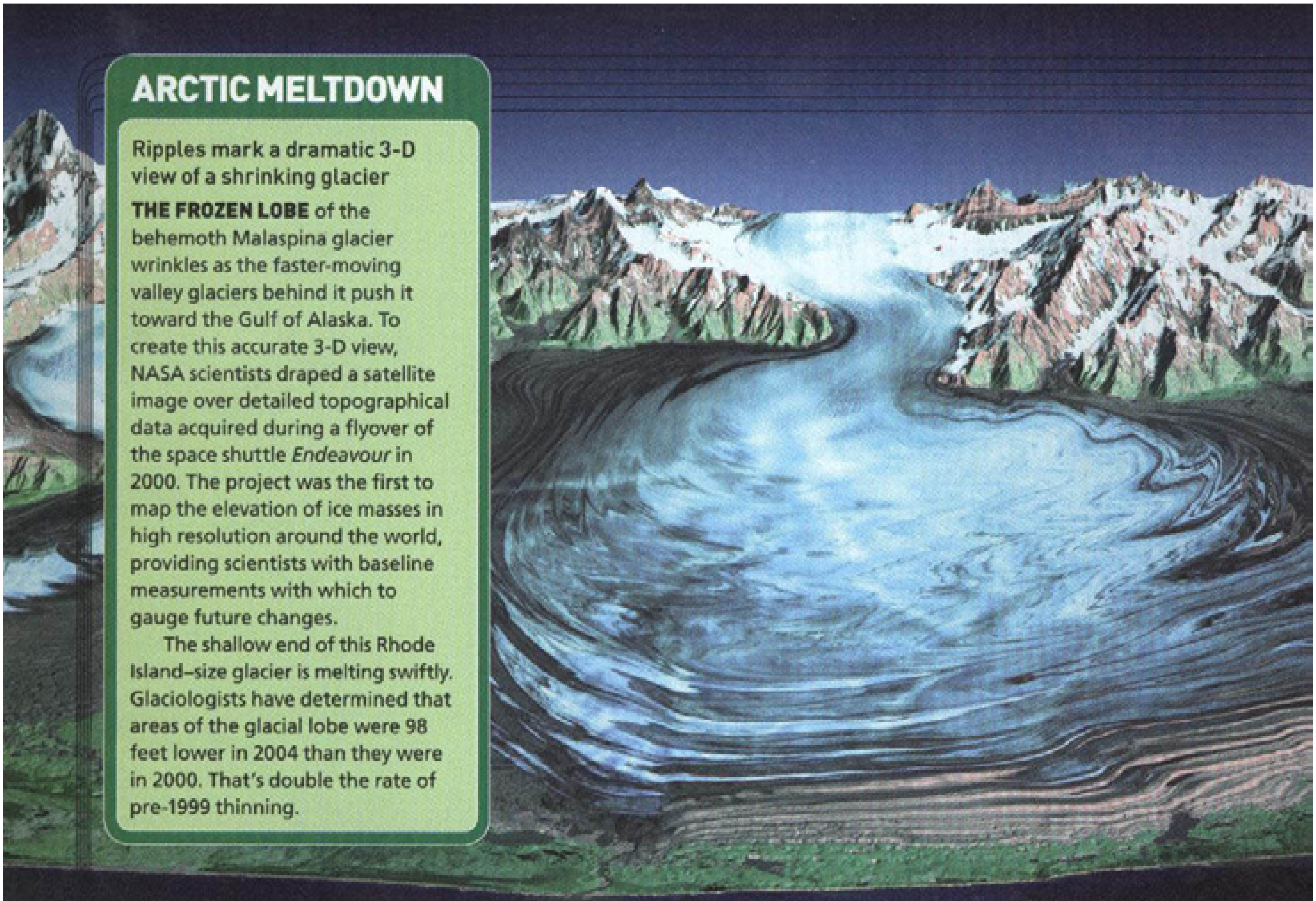


## ARCTIC MELTDOWN

Ripples mark a dramatic 3-D view of a shrinking glacier

**THE FROZEN LOBE** of the behemoth Malaspina glacier wrinkles as the faster-moving valley glaciers behind it push it toward the Gulf of Alaska. To create this accurate 3-D view, NASA scientists draped a satellite image over detailed topographical data acquired during a flyover of the space shuttle *Endeavour* in 2000. The project was the first to map the elevation of ice masses in high resolution around the world, providing scientists with baseline measurements with which to gauge future changes.

The shallow end of this Rhode Island–size glacier is melting swiftly. Glaciologists have determined that areas of the glacial lobe were 98 feet lower in 2004 than they were in 2000. That's double the rate of pre-1999 thinning.

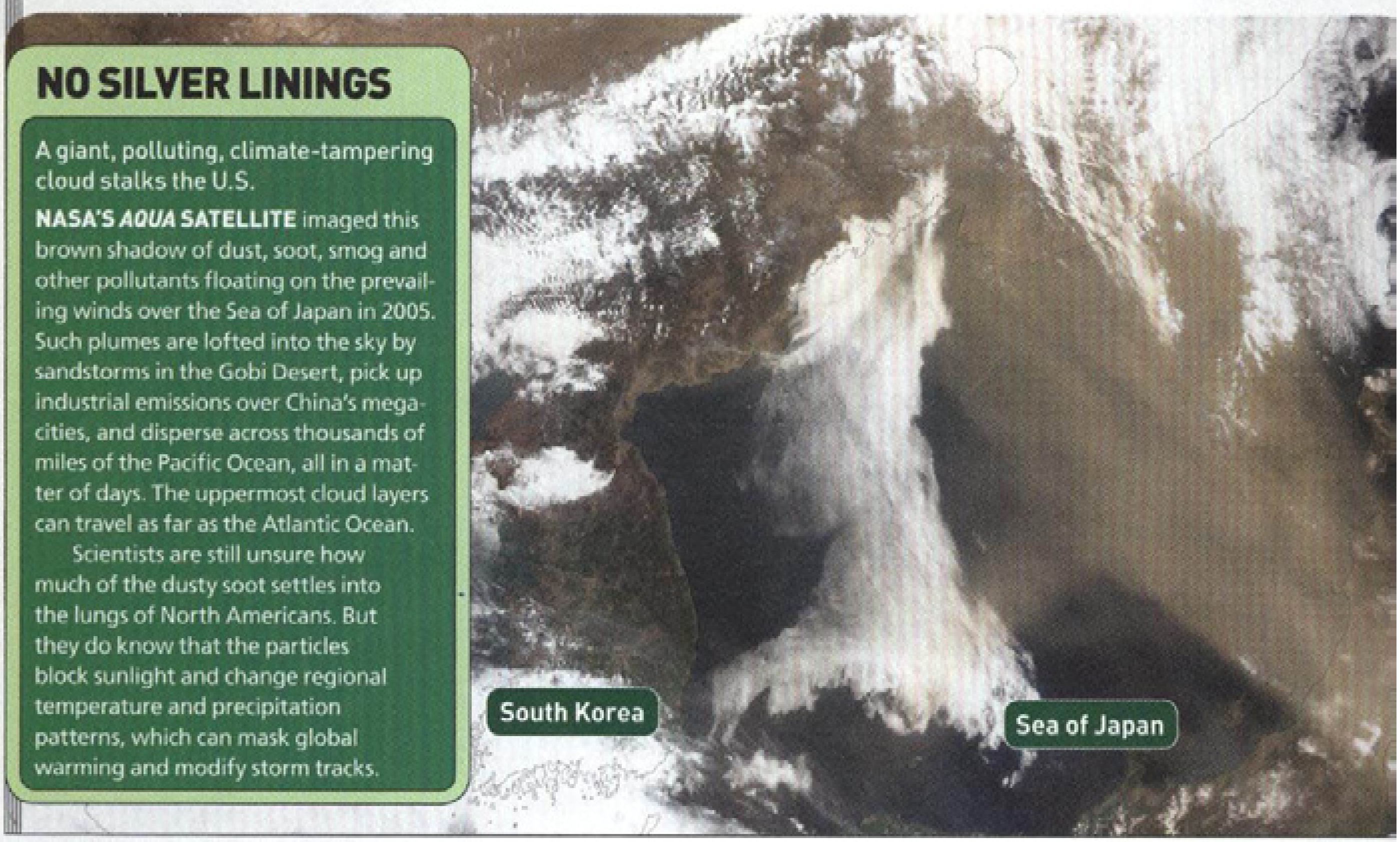


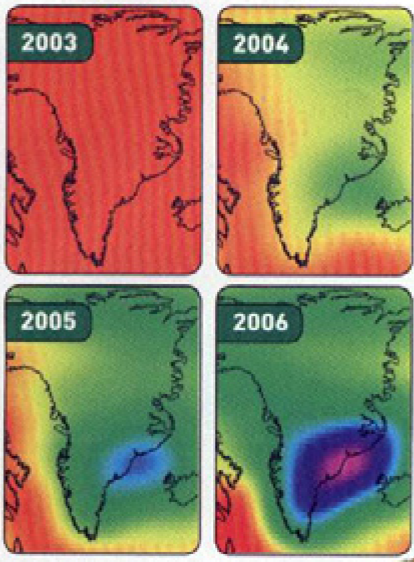
## NO SILVER LININGS

A giant, polluting, climate-tampering cloud stalks the U.S.

**NASA'S *AQUA* SATELLITE** imaged this brown shadow of dust, soot, smog and other pollutants floating on the prevailing winds over the Sea of Japan in 2005. Such plumes are lofted into the sky by sandstorms in the Gobi Desert, pick up industrial emissions over China's megacities, and disperse across thousands of miles of the Pacific Ocean, all in a matter of days. The uppermost cloud layers can travel as far as the Atlantic Ocean.

Scientists are still unsure how much of the dusty soot settles into the lungs of North Americans. But they do know that the particles block sunlight and change regional temperature and precipitation patterns, which can mask global warming and modify storm tracks.





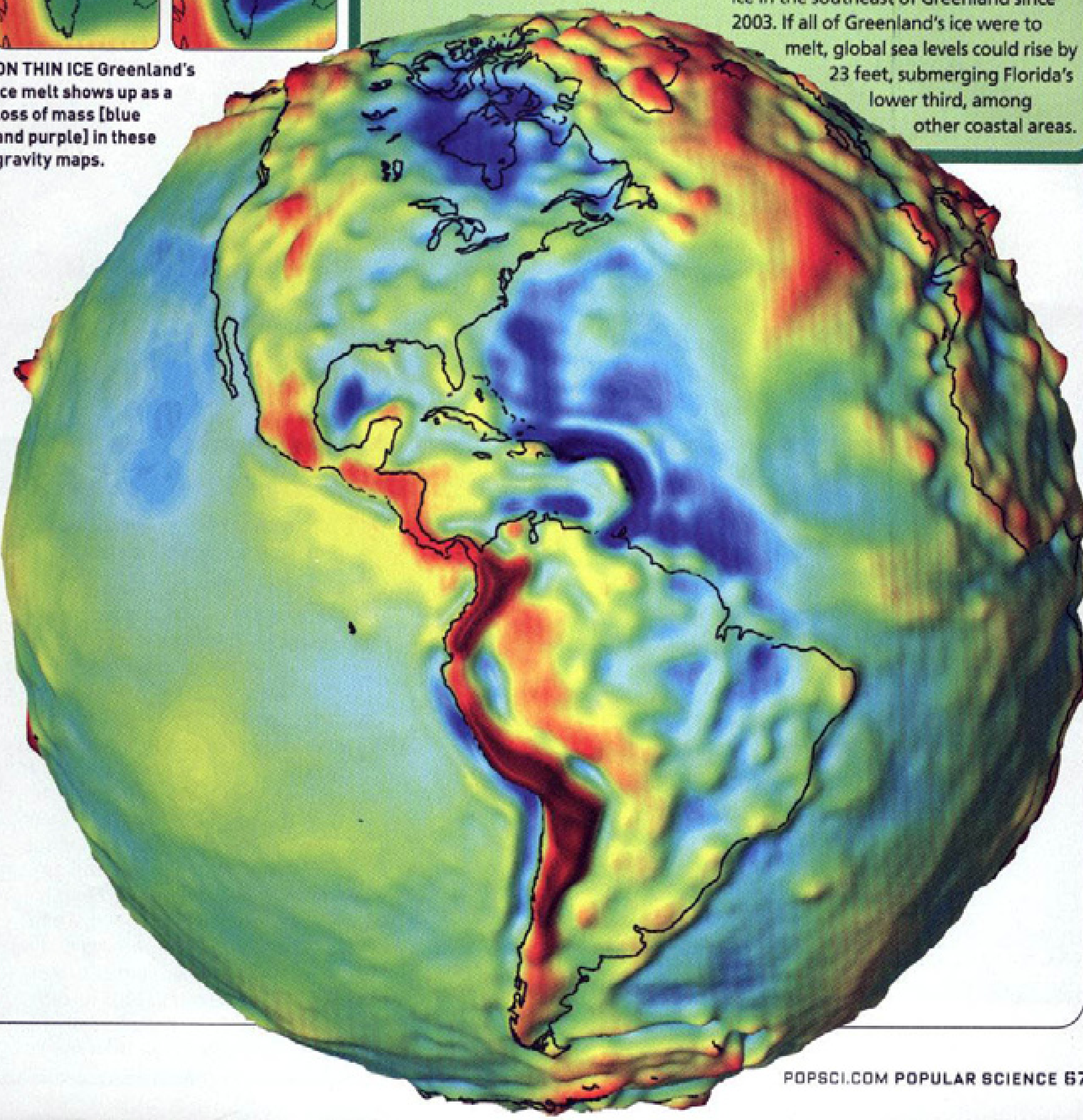

ON THIN ICE Greenland's ice melt shows up as a loss of mass [blue and purple] in these gravity maps.

# GLOBAL WARMING MEANS *MASSIVE* CHANGE

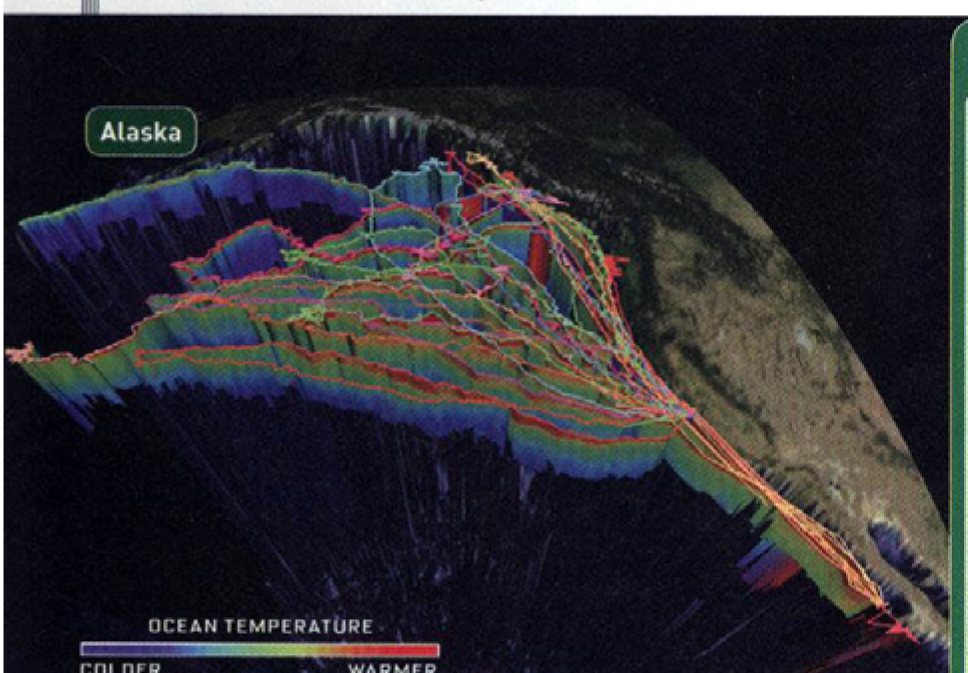
**The first satellite to measure subtle differences in Earth's gravitational field is helping scientists quantify the effects of climate change**

**FORGET WHAT YOU** learned in high school: The pull of Earth's gravity is not 9.81 meters per second squared everywhere. For proof, look no further than this global gravity map, which shows where Earth's gravitational force is stronger or weaker. Red indicates areas of high mass—often mountain chains—that exert extra gravitational pull.

This image is based on data captured by the twin satellites of NASA's *Gravity Recovery and Climate Experiment*, or *GRACE*, from 2003 to 2006. The satellites measure the gravity of the entire planet every 30 days. Because *GRACE* detects mass, it can track where ice accumulates and melts on Earth's crust, providing a critical gauge of global warming. For instance, it has enabled scientists to quantify the dramatic loss of ice in the southeast of Greenland since 2003. If all of Greenland's ice were to melt, global sea levels could rise by 23 feet, submerging Florida's lower third, among other coastal areas.



THIS PAGE: GLOBE: NASA'S GRAVITY RECOVERY AND CLIMATE EXPERIMENT; IMAGE: UNIVERSITY OF TEXAS CENTER FOR SPACE RESEARCH; PRECEDING PAGE, FROM TOP: NASA/JPL-CALTECH; DATA: NASA SHUTTLE RADAR TOPOGRAPHY MISSION (ELEVATION) AND NASA/USGS LANDSAT SATELLITE, THEMATIC MAPPER SENSOR (OVERLAY); JESSE ALLEN/NASA EARTH OBSERVATORY; DATA: MODIS RAPID RESPONSE TEAM AND GODDARD EARTH SCIENCES

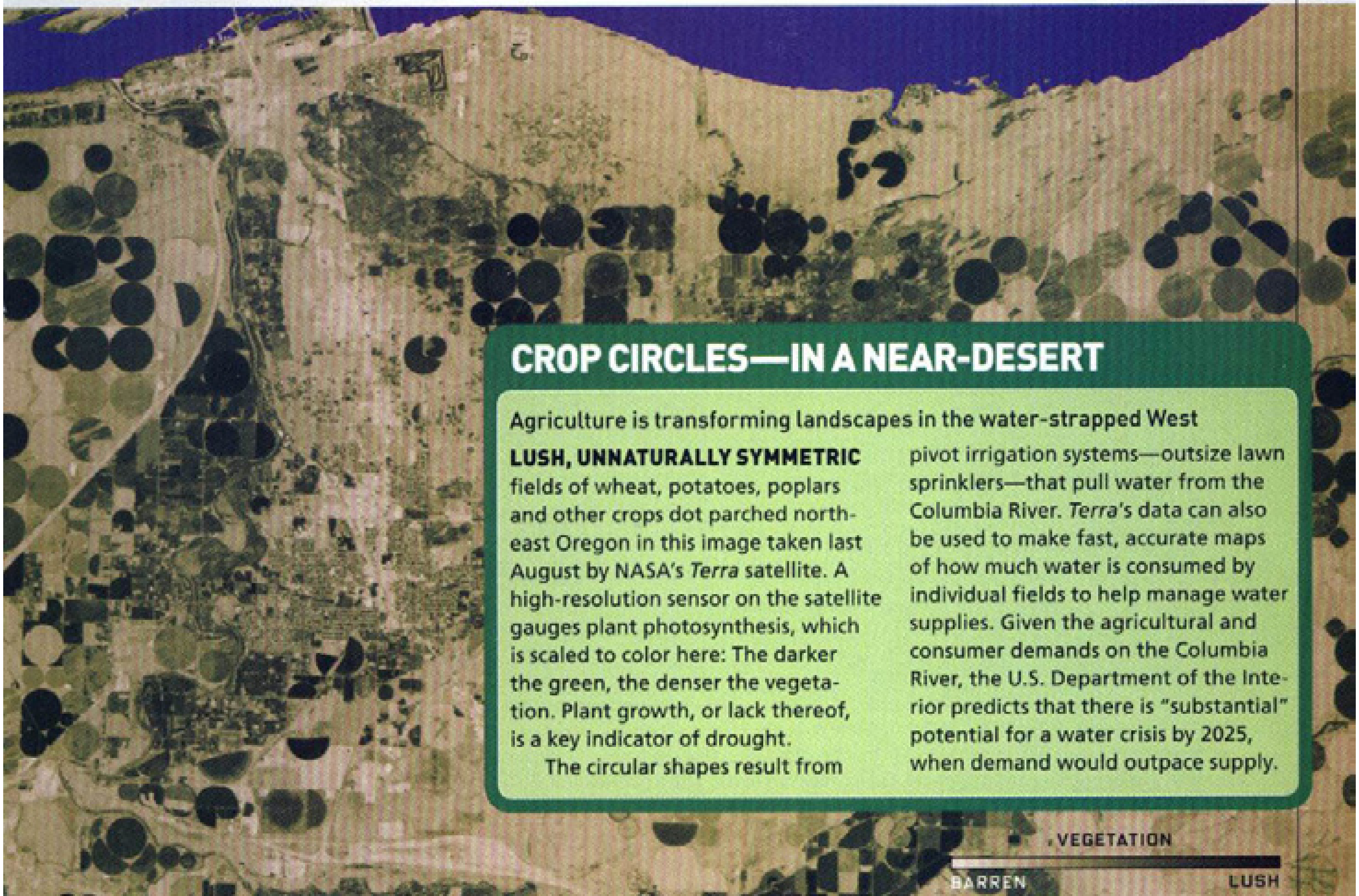




## SEALS FROM SPACE

Sea creatures are our next army of environmental-data collectors

**MEET THE NEWEST** ocean sensors: elephant seals. These zigzags represent the migration patterns of 11 females between Baja California and the Gulf of Alaska. iPod-size satellite tags glued to their heads recorded the depth, temperature and salinity of the water they swam through and then relayed the data to researchers. The Tagging of Pacific Pelagics initiative, a program of the Census of Marine Life, plans to outfit 23 marine species, including bluefin tuna and white sharks, with 6,000 tags by 2010. One surprising finding so far: A weird warming of California coastal waters in 2005 forced tagged sea lions to venture offshore up to 300 miles in search of food.

FROM TOP: JESSE ALLEN/NASA EARTH OBSERVATORY; DATA: NASA/GSFC/METI/ERSDAC/JAROS AND U.S./JAPAN ASTER SCIENCE TEAM; DAN COSTA/TOPP; DATA: FROM TAGS AND SOFTWARE DESIGNED BY UNIVERSITY OF ST. ANDREWS SEA MAMMAL RESEARCH UNIT




## CROP CIRCLES—IN A NEAR-DESERT

Agriculture is transforming landscapes in the water-strapped West

**LUSH, UNNATURALLY SYMMETRIC** fields of wheat, potatoes, poplars and other crops dot parched northeast Oregon in this image taken last August by NASA's *Terra* satellite. A high-resolution sensor on the satellite gauges plant photosynthesis, which is scaled to color here: The darker the green, the denser the vegetation. Plant growth, or lack thereof, is a key indicator of drought.

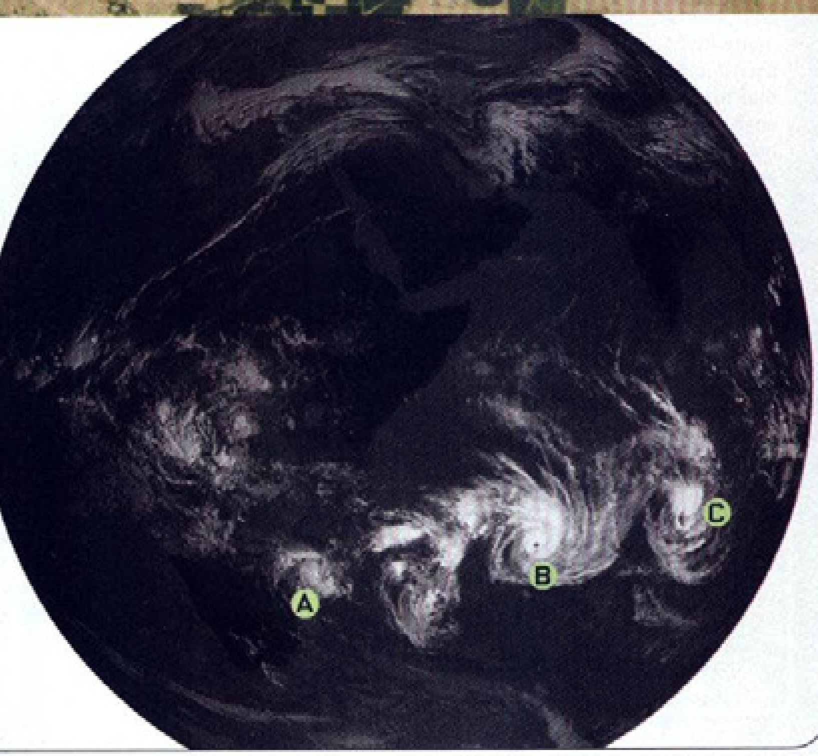
The circular shapes result from pivot irrigation systems—outsize lawn sprinklers—that pull water from the Columbia River. *Terra*'s data can also be used to make fast, accurate maps of how much water is consumed by individual fields to help manage water supplies. Given the agricultural and consumer demands on the Columbia River, the U.S. Department of the Interior predicts that there is "substantial" potential for a water crisis by 2025, when demand would outpace supply.

## IT'S COLD AT THE TOP

If the world is getting stormier, these satellites could show it

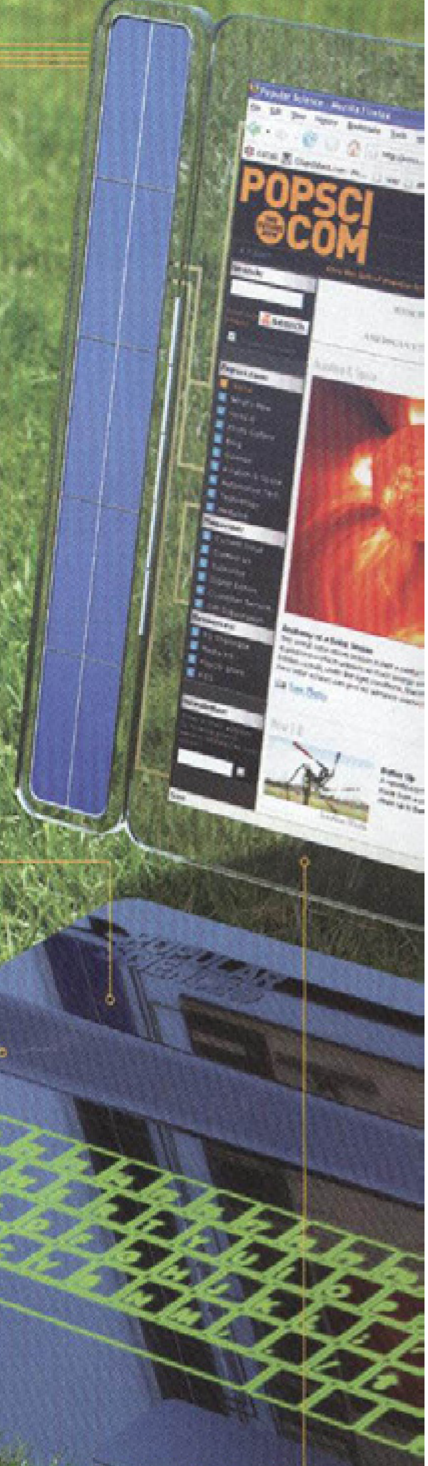
**YOU'RE SEEING** the frigid tops of Earth's clouds captured in a single moment in February, the height of the Pacific cyclone season. Cyclones Favio [A], Gamede [B] and Humba [C] spin toward Africa. This seamless mosaic, developed by NOAA's Climate Prediction Center, stitches together strips of data from five weather satellites. Their sensors measure infrared radiation (heat) in the atmosphere, so the colder the cloud, the whiter its trace. The ghostly shapes of continents appear dark because the sun warms landmasses in the daytime.

The data set, which is captured every half-hour, is the first to deliver a whole-Earth, near-real-time view of how storm systems evolve.




ARLENE DUCAO; DATA: NOAA CLIMATE PREDICTION CENTER

# BLUEPRINT FOR A GREEN LAPTOP




**In 2009, worldwide laptop sales are expected to surpass desktop sales for the first time—reaching more than 150 million. Most people will keep a laptop for just three years or so before shelving it or tossing it onto a junk heap. Here's how designers plan to make this ubiquitous gadget more eco-friendly across its entire life span, from manufacture to recycling** BY LAUREN AARONSON

## PROBLEM: PETROLEUM-FILLED PLASTIC

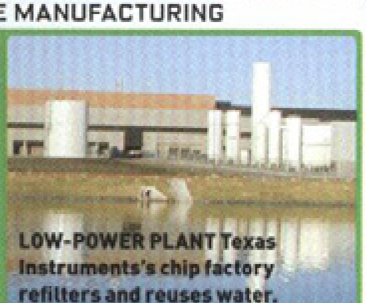
**SOLUTION: MAKE CASES FROM CORN** New bioplastics—plant-based polymers—require less oil and energy to produce than traditional plastics. One challenge: upping heat resistance so electronics won't melt them. Fujitsu makes a laptop with a half-natural, half-conventional case and is now testing a castor-oil plastic that's up to 80 percent bio-content.

## PROBLEM: LANDING IN LANDFILLS

**SOLUTION: UPGRADE, DON'T TRASH** The EPA estimates that Americans discard 19,000 tons of laptops a year. But soon it may get easier (and cheaper) to upgrade your laptop than to replace it, keeping e-waste out of dumps and saving the energy and materials needed for a whole new computer. Laptop-maker Asus recently released a model that lets users change the processor, graphics card and other parts just by removing one panel, instead of spending hours disassembling the computer.

## PROBLEM: ENERGY-INTENSIVE MANUFACTURING

**SOLUTION: BUILD MORE-EFFICIENT FACTORIES**
Producing a laptop requires nearly as much energy as it will use over the rest of its life, but new plants may slash this consumption. One of the world's greenest computer-chip factories could go online as early as 2009. The Texas Instruments plant in Richardson, Texas, will consume 20 percent less electricity and 35 percent less water, spit out 50 percent fewer nitrogen oxides—and cost 30 percent less to build—than TI's previous plant. In one energy-saving measure, the plant uses the waste heat generated by its huge air conditioners to warm water for free, eliminating the need for four polluting gas boilers.



**LOW-POWER PLANT** Texas Instruments's chip factory refilters and reuses water.

## PROBLEM: POWER-SUCKING DISPLAYS

**SOLUTION: CREATE GREENER LIGHT**
An LCD can eat more than half of a laptop's power, mostly due to its fluorescent backlight. Some laptops are lit with more-efficient LEDs instead, but the next step may be to nix backlights altogether. Displays made of OLEDs, or organic light-emitting diodes, form images with electroluminescent films. In small sizes, as in cellphones, OLEDs can significantly cut power use (depending on the image's colors); companies hope that this advantage will scale up.



ILLUSTRATION: MAT DARTFORD; INSET PHOTOGRAPH: COURTESY TEXAS INSTRUMENTS; SOURCES FOR LIFE-CYCLE ASSESSMENTS: ERIC MASANET/LAWRENCE BERKELEY NATIONAL LABORATORY; ERIC WILLIAMS/ARIZONA STATE UNIVERSITY


**PROBLEM: GUZZLING POWER FROM THE GRID**

**SOLUTION: HARNESS THE SUN** Portable solar chargers suited for laptops already exist. A company called MSI Computer has even developed a prototype laptop with photovoltaic cells integrated directly into its case.

**PROBLEM: TOXIC WASTE**

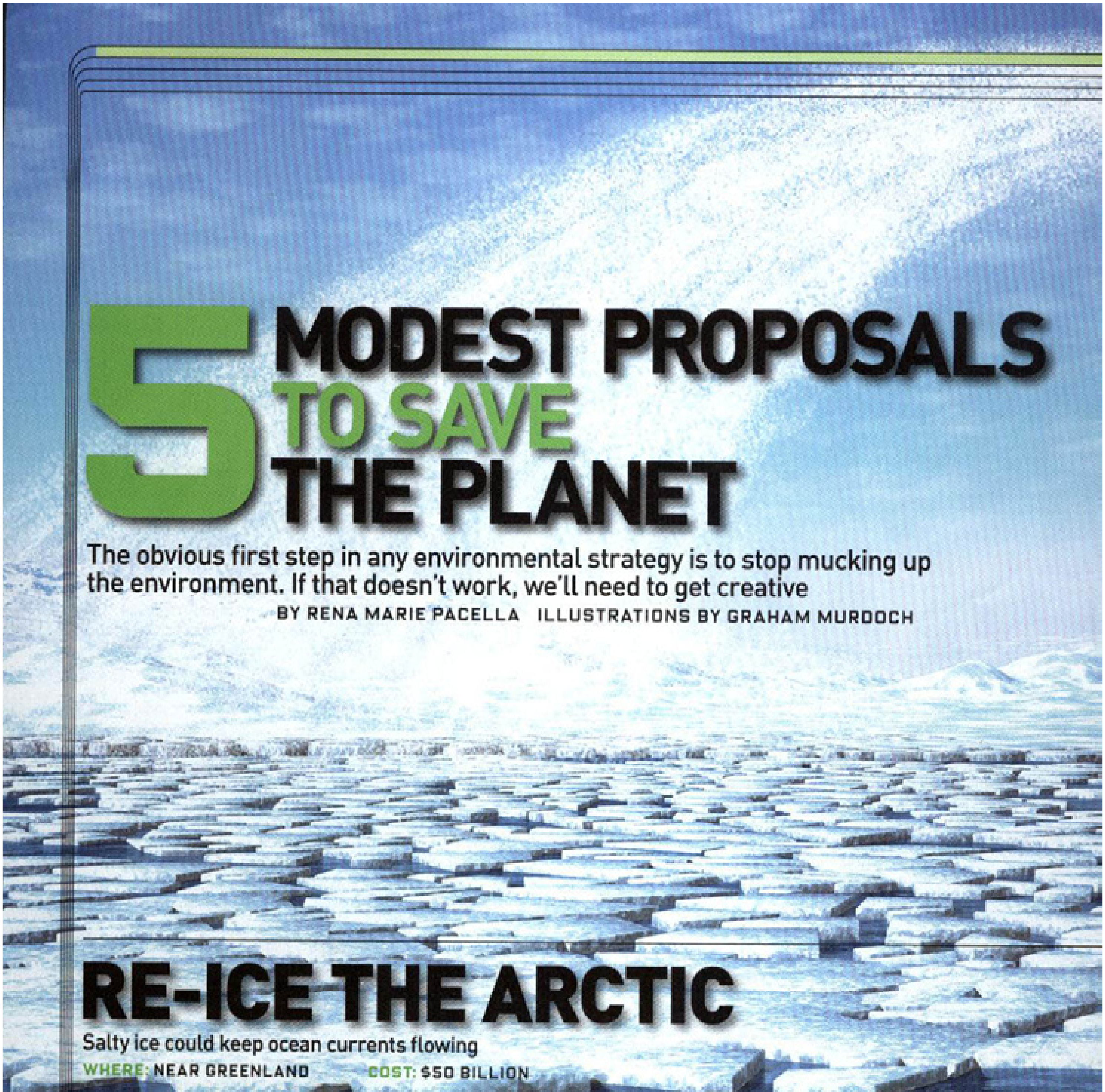
**SOLUTION: GET THE LEAD OUT** Concerned that dumped gadgets could leak poisons, the law is cracking down on dangerous ingredients. (The lead in solder, for example, is now being replaced by silver and copper.) Last year, the European Union enacted legal limits on toxins in electronics sold there, and the U.S. introduced a similar (though voluntary) rating system for computers. President Bush recently mandated that 95 percent of government-purchased electronics meet the American eco-standards, eliminating about 3,000 tons of hazardous waste by 2011.

**PROBLEM: TRICKY RECYCLING**

**SOLUTION: MAKE A DIGITAL PARTS LIST** Recycling computers can be expensive and time-consuming. Dismantlers usually pull out valuable parts for reuse or resale, but they have to examine each computer individually to determine what's in it. If manufacturers add a radio-frequency ID tag to a laptop, says Valerie Thomas of Georgia Tech, it could instantly tell recyclers how to recover components.

**PROBLEM: THAT SPINNING HARD DRIVE**

**SOLUTION: SWITCH TO FLASH MEMORY** Future laptops could knock 10 percent off their energy use just by replacing hard drives with solid-state, or flash, memory, which has no watt-hungry moving parts. Dell debuted a laptop with a 32-gigabyte solid-state drive this year. By 2012, manufacturer Samsung says, the drives may hold about 30 times as much data.



# 5 MODEST PROPOSALS TO SAVE THE PLANET

The obvious first step in any environmental strategy is to stop mucking up the environment. If that doesn't work, we'll need to get creative

BY RENA MARIE PACELLA ILLUSTRATIONS BY GRAHAM MURDOCH

## RE-ICE THE ARCTIC

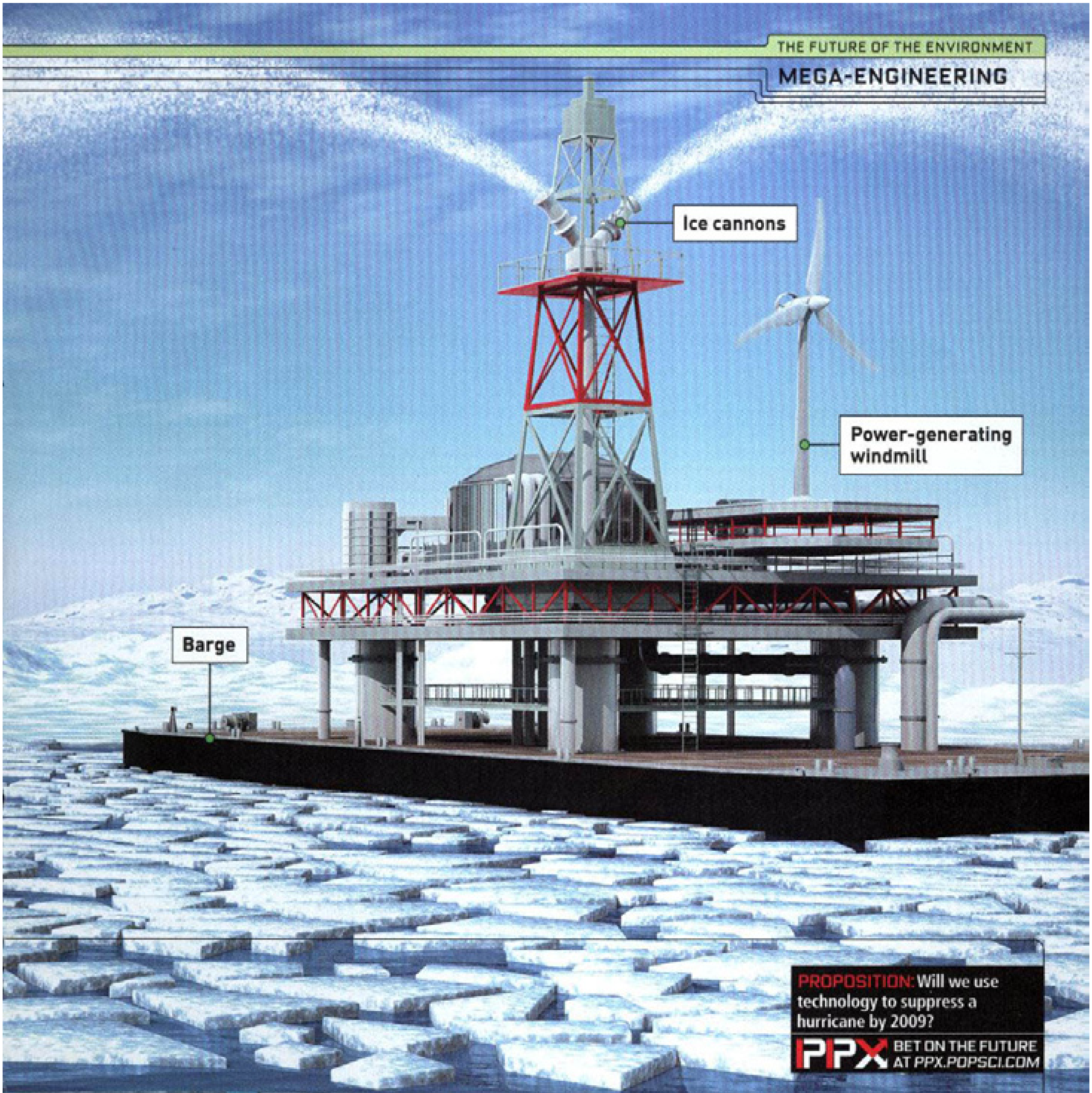
Salty ice could keep ocean currents flowing

**WHERE:** NEAR GREENLAND **COST:** $50 BILLION

**THE PROBLEM:** Arctic ice is melting, diluting the salty seas with freshwater and, many suspect, weakening the ocean currents that help regulate the global climate by transporting heat around the globe. If these currents were to shut down, the consequences would be unpredictable and dire: immense loss of marine life and fisheries; a reduction in the ability of the ocean to remove greenhouse gases from the atmosphere; and, some scientists speculate, drastic cooling of Northern Europe.

**THE FIX:** Make more Arctic ice, and make it salty. Under normal conditions, warm-water currents like the Gulf Stream carry heat from the tropics to Europe. After a current releases its heat, the water sinks (cold water is more dense than warm; salty more dense than fresh) and flows back to the equatorial regions along the ocean floor. This sinking is the engine that powers global currents. But in one apocalyptic scenario, melted Arctic ice dilutes the water in the North Atlantic to the point where the tropics-bound current isn't dense enough to sink. The heat-carrying currents skid to a halt, and Europe enters a new ice age.

Industrial engineer Peter Flynn of

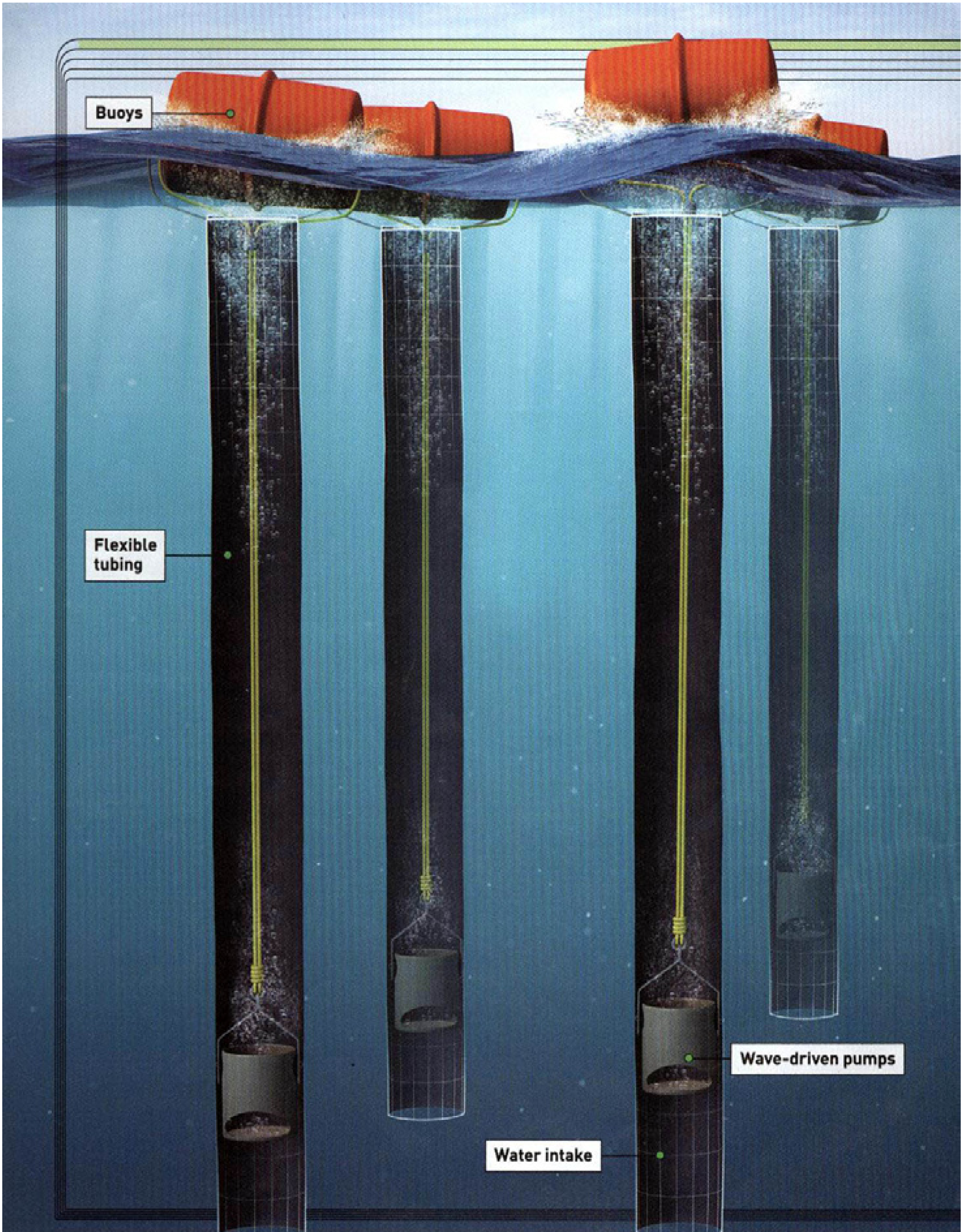





the University of Alberta proposes a bold way to boost currents if they begin to slacken: Tow 8,000 ice-making barges to the Arctic, and make a salty ice cube the size of New Mexico. In this plan, the barges would arrive off the coast of Greenland in the fall. As winter set in and air temperatures fell below 14°F, wind-powered water pumps on the barges would shower salty seawater on top of the existing ice pack, creating new layers of extremely salty ice.

Come spring, the barges would boost the currents by spraying more water onto the newly formed saline ice pack. As it melted, the cold, dense, salty water would sink into the deep ocean. The result: a 6 percent increase in down-welling currents, enough to keep the system moving along.

**NEXT STEPS:** Flynn does not advocate implementing this solution now —only if the slowdown reaches a critical threshold (what that threshold is and when it may occur is still in question) and only if all else fails. It's not a plan B, he says; it's a plan D. Instead, a better course of action would be to ensure that the down-welling currents and ocean conveyor belt not be suppressed in the first place.


Buoys
Flexible tubing
Wave-driven pumps
Water intake

# TAME STORMS WITH COLD WATER

**A million straws could mellow the next Katrina**

**WHERE:** GULF OF MEXICO **COST:** $5 BILLION

**THE PROBLEM:** Climate change is warming the oceans. Warm oceans fuel hurricanes, which draw their energy from the heated, moist air at the sea surface. As sea temperatures continue to rise, some scientists warn that tropical storms will intensify.

**THE FIX:** Cool down the warm surface water that storms need to grow. New Mexico inventor Phil Kithil wants to put 1.6 million ocean-cooling "pumps" into the Gulf of Mexico, anchor them to the seafloor, and watch as they turn category-4 whoppers into category 3s, and 3s into 2s. It would take four months, some 100 barges and $5 billion to install, but once in place, the 1,000-mile-long band of water coolers would kick in whenever a storm started brewing.

Next month, Kithil will set sail for Bermuda with 10 of his wave-powered pumps and attempt to cool a one-third-square-mile patch of sea. Dropped from the deck of his ship, spools of barrel-width flexible tubing will unravel to form 650-foot-long cylinders. These are topped by buoys that bob up and down with each passing wave and drive pumps that draw cool, nutrient-rich water up from the deep ocean. Bigger waves mean more cooling, and, conveniently, big waves precede hurricanes. "So we get cooling only when we want cooling," Kithil says, "when there's a hurricane on the horizon."

His company, Atmocean, has already tested individual pumps, and they temporarily lowered surface temperature by 7°F. The results might not be so dramatic in the large-scale trial, but models show that even a 1°F drop would reduce hurricane winds by 5 percent. According to Kithil, a drop in wind speed from 120 to 110 mph would reduce property damage by 23 percent.

**NEXT STEPS:** Kithil's team will measure the effects on marine life. They hypothesize that the water's increased nutrient levels will improve the health of the ocean food chain and possibly enhance the ocean's natural ability to sequester carbon by encouraging the growth of plankton (also a food source for fish) near the sea surface.

# GROW SUPER-TREES IN FACTORIES

**How robot-run factories will save the rainforest**

**WHERE:** RAINFORESTS **COST:** $120,000 PER SQUARE MILE

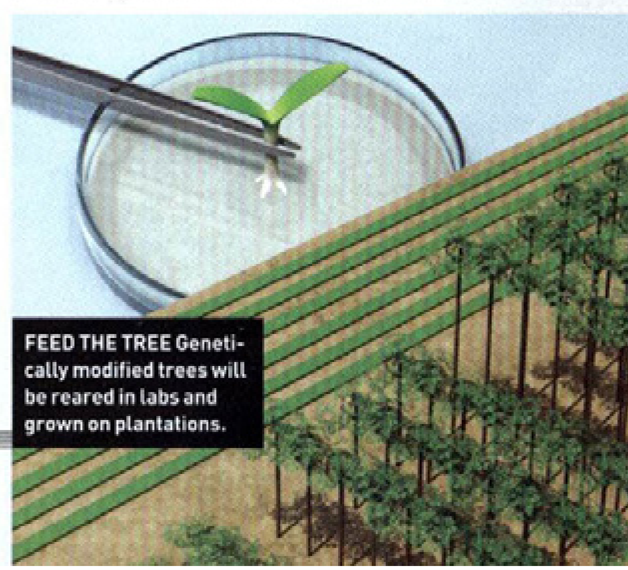
**THE PROBLEM:** The world's rainforests lose 100,000 acres and as many as 100 species every day. The Amazon alone loses 10,000 square miles a year. As the demand for timber (used for wood, paper and biofuel, among other products) increases, experts predict that the rainforests could be wiped out by 2050—and with them, the habitat for half of the world's species of plants, animals and microorganisms and the source of 25 percent of all pharmaceuticals.

**THE FIX:** Genetically modified tree plantations that will undercut the market for cheap rainforest wood. ArborGen, a biotech company in Charleston, South Carolina, is spearheading research that will help farmers mass-produce trees on 5 percent of the land currently required. It will also eliminate the need to ever again fell a native rainforest tree for timber (clear-cutting for farmland will not be affected).

Since 2000, the company has been identifying useful genes from half a dozen tree and plant species to produce trees with desirable traits like fast growth, stress tolerance and reduced lignin (the material that must be chemically removed to make paper). For example, by speeding up the trees' growth cycle, ArborGen is on track to decreasing the time it takes to harvest pine trees from roughly 30 years to about 18. It's also created a low-lignin eucalyptus tree that's perfect for pulping.

The two big hurdles are time and money. Transgenic trees are painstaking and expensive to cultivate. Even after scientists develop a new line of trees, they must still handle each seedling individually, from petri dish to plantation.

**NEXT STEPS:** To make this approach economically viable, ArborGen plans to churn out the designer seedlings in fully automated tree factories, so it has begun designing the robots that will transplant and evaluate seedlings autonomously. The company hopes it can also save endangered tree species—one project aims to splice blight-resistance genes into the near-extinct American chestnut tree.



**FEED THE TREE** Genetically modified trees will be reared in labs and grown on plantations.

# BUILD WETLANDS FROM SCRATCH

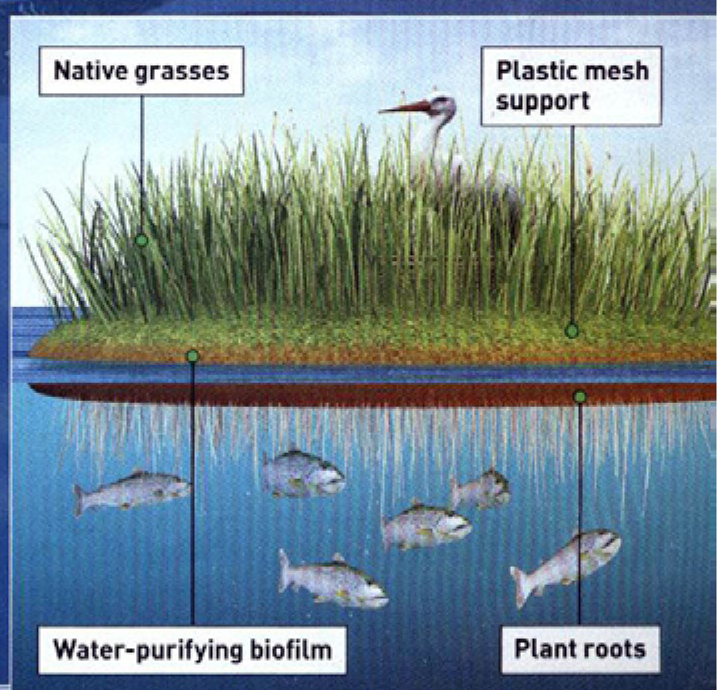
## Save coastal marshes and clean up polluted waterways with plant-covered rafts

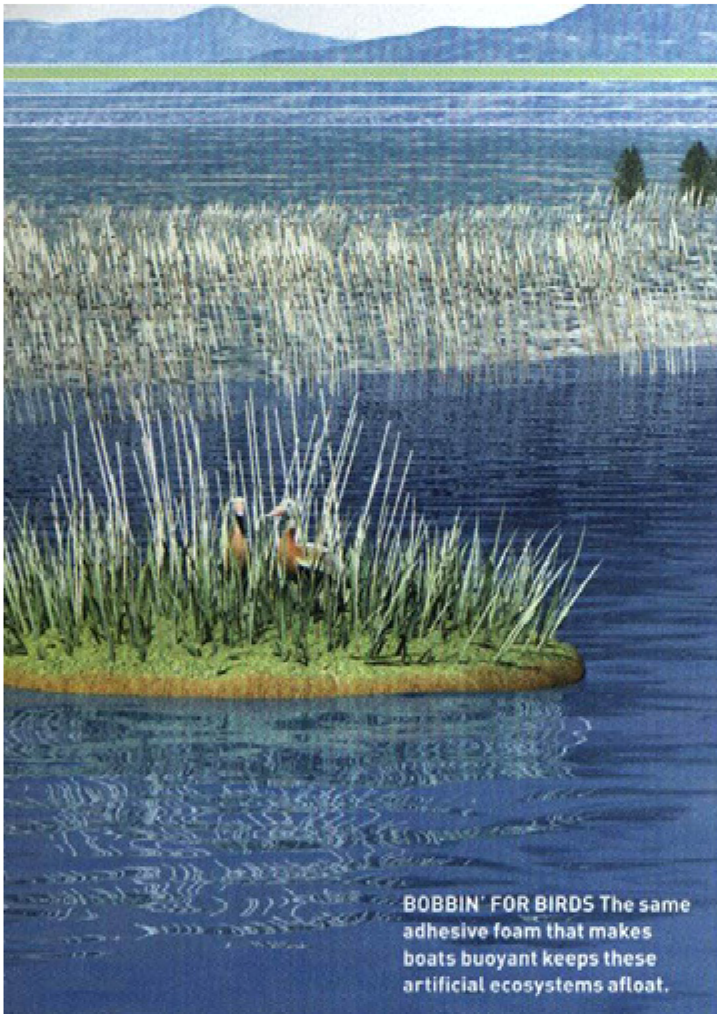
**THE PROBLEM:** The wetlands are losing ground. Crops and condos are rapidly overtaking much of the waterlogged land—home to thousands of bird and animal species—while pollution and sea-level rises take care of the rest. With this loss comes drastically reduced water quality, increased flooding of surrounding areas and the looming specter of the extinction of many species.

**THE FIX:** Construct archipelagos of boat-size to basketball-court-size islands out of recycled plastic and foam, plant habitat-specific vegetation, and set the islands afloat wherever natural wetlands once thrived.

Along with rainforests and coral reefs, wetlands are the most active and diverse ecosystems on the planet, serving as a home or breeding ground to one third of all bird species, 190 amphibians and more than 200 types of fish. Wetlands filter out excess nutrients and pollutants by trapping them in roots and soil where plants and bacteria break them down into less harmful substances.

To mimic wetlands, inventor Bruce Kania starts with layers of polymer mesh bonded together with adhesive foam and carpets them with sod and wetland vegetation. Plants are





BOBBIN' FOR BIRDS The same adhesive foam that makes boats buoyant keeps these artificial ecosystems afloat.

WHERE: COASTAL AREAS
COST: $800 MILLION PER SQUARE MILE OF ISLAND

selected to attract insects, frogs, waterfowl, beavers or whatever wildlife is native to the area. As the plants grow, their roots weave their way through the plastic matrix to the water below. Microbes cling to the polymer fibers and colonize the root system, forming a slimy layer of "biofilm" that purifies the water and oxygenates it. (It is unclear whether the islands will help limit flooding.)

Kania first tested his "BioHavens" in algae-infested ponds on his farm in Montana. The BioHavens filtered fertilizer runoff and suppressed harmful algal blooms in the ponds. Now some 3,000 of these ready-made ecosystems are floating at trouble spots around the globe, including a chain of BioHavens in a reservoir in Singapore that absorb waterborne pollutants.

**NEXT STEPS:** Kania is confident that his islands work, but he may soon receive independent data that will prove it. Consulting engineer Frank Stewart, with a two-year grant from the state of Montana, is wrapping up water-quality tests conducted on the BioHavens in huge fish tanks. They could provide the first solid evidence that the islands clean water.

# INSULATE THE GLACIERS

## Huge blankets in the Alps could prevent a big thaw

WHERE: SWISS ALPS  COST: $12 MILLION PER SQUARE MILE

**THE PROBLEM:** Glaciers—Earth's largest freshwater reservoir, collectively covering an area the size of South America—are melting away, shrinking by up to hundreds of feet per year in some places. The Alps alone stand to lose three quarters of its glaciers by 2050, and what's left by the end of the century.

**THE FIX:** Wrap thawing glaciers in football-field-size synthetic blankets that keep the cold in and the heat out. At least that's what ski resorts in the Swiss Alps are doing. Tired of risking the fate of their industry on the global community's ability to get a grip on rapid climate change, more than a dozen resorts turned to local textile company Fritz Landolt to stop the melting. Called the Ice Protector, Landolt's material is a tough but lightweight dual-layer composite. On top is polyester to reflect ultraviolet light, and on the bottom is polypropylene, a polymer used in military clothing and auto parts, to block heat. When wrapped around a glacier, it prevents the top snow layer—and, it's hoped, the permanent ice underneath—from melting in the summer sun.

After a small pilot project in 2005 on the shrinking Gurschen glacier proved hugely successful—the blanketed area had 80 percent less melt than surrounding ice and snow two years in a row—Landolt has been tackling bigger and bigger ice packs, including an area the size of six football fields (more than 300,000 square feet) on the Vorab glacier, home to one of Switzerland's largest ski resorts.

**NEXT STEPS:** Don't count on the blankets saving the snows of Kilimanjaro. With the ski resorts footing the bill, their use is limited to critical areas where melt directly interferes with skiing and snowboarding. But there's always the burgeoning beer market. "We had a guy throwing an outdoor party last summer," says Landolt product manager Marcel Stahle. "We sold him 100 square feet. His beer stayed cold all day."

EASY DOES IT Six people can roll out 15 of these 330-foot glacier blankets in two weeks.