Unmasking a Shifty Climate System

Oceans are supposed to be a steadying influence on climate, but now they are being linked to abrupt, decades-long shifts that could be harbingers of climate change to come

NICHOLAS GRAHAM WELL REMEMBERS THE winter of 1976-77. Then a part-time marine forecaster in California and a surfer, he had his finger on the pulse of the North Pacific Ocean, across which much of North America's weather must pass. And the ocean beast was feeling decidedly out of sorts that winter. Storms that would usually drench Seattle were barreling into Alaska. Unusually powerful storms farther away in the North Pacific were assaulting the California coast with one set of towering waves after another. And all the while Alaska, of all places, was basking in unseasonable warmth.

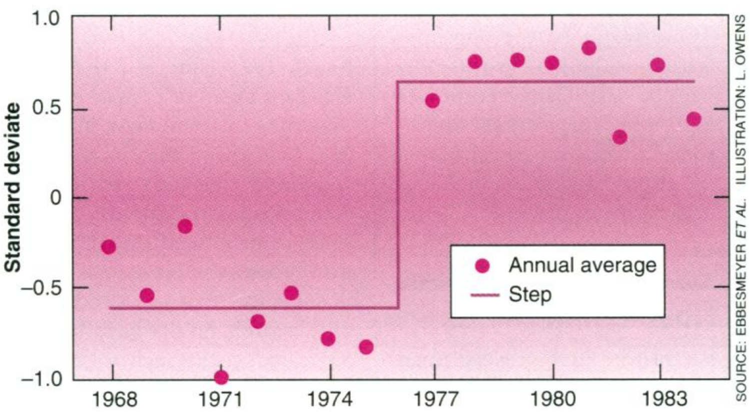
Graham, now a climate researcher at the Scripps Institution of Oceanography, has lately come to recognize that winter for what it was: the start of a new climate regime that stretched across the Pacific and North America as far as the East Coast, one that lasted more than a decade before returning to "normal." And, in searching for an explanation, Graham and others have come up with unsettling evidence that the ocean—and the climate system that is so intimately entwined with it—can abruptly switch to a new mode of operation that can last for a decade or more. The climate shift that gripped a good part of the Northern Hemisphere turns out to have been a new side to a familiar phenomenon—El Niño. In essence, the on-off seesaw of El Niño, which ordinarily floods the eastern Pacific with warm water every 3 or 4 years, got stuck part way "on" for 10 years straight, prolonging the wild weather that El Niño often brings (*Science*, 24 January, p. 402).

No one knows why the tropical Pacific Ocean got out of whack in 1976. But together with a puzzling shift in the behavior of the North Atlantic, where rapid cooling in the late 1960s and 1970s coincided with harsh winters in Europe and a temporary cooling of the Northern Hemisphere (see box), the discovery is raising concerns about Earth's climatic future. Could oceanic shifts and the climate changes they bring be masking greenhouse warming, perhaps lulling us into ill-advised complacency? Could greenhouse warming somehow be at the root of such decades-long climate shifts? Will greenhouse warming itself come in disruptive jumps?

Answers will be frustratingly slow in coming, since the study of these ocean-driven climate shifts is in its infancy. "Ten years ago we didn't have the evidence for these decade-scale changes" in the ocean, says Sydney Levitus, an oceanographer with the National Oceanic and Atmospheric Administration (NOAA) in Washington, D.C. "Now they're showing up everywhere. It's just amazing what's going on."

One obstacle to recognizing them has been the time they span. Since these shifts tend to be smaller than year-to-year fluctuations and to involve several parts of the climate system, recognizing them takes detailed, decades-long records of climate and ocean. Such records are scarce, and the time scale presents another problem as well. Even the 2- to 3-year duration of an El Niño "is right on the edge of our attention span and the time scale of a [research] grant," explains Arnold Gordon of Columbia University's Lamont-Doherty Geological Observatory, who heads a new NOAA study of ocean-atmosphere interaction in the Atlantic. Puzzling out the causes and effects of these decade-long changes puts even greater strains on meteorologists' and oceanographers' customary time frames.

Still, by the end of the 1980s it was hard to overlook some of the effects of the Pacific climate shift that began in 1976. During the 8 years beginning in January 1977, five severe freezes struck the citrus groves of Florida after 75 years that saw an average of just one major freeze per decade, according to a study by Jeffrey Rogers and Robert Rohli of Ohio State University. On the West Coast, Richard Seymour of the Scripps Institution of Oceanography and his colleagues found that waves higher than 6 meters ravaged Southern California 10 times between 1980 and 1984, compared to eight times in the previous 80 years.



Something sudden in the Pacific. *A composite of 40 environmental variables jumped to a new state after 1976.*

To gauge the full extent of the 1976 climate shift, a group of Pacific climate researchers led by oceanographer Curtis Ebbesmeyer of Evans Hamilton Inc. in Seattle combined records of 40 environmental variables that reflected conditions around the Pacific region in general and the Puget Sound area in particular over the period from 1968 through 1984. The variables included the number of Canada goose nests on the Columbia River, the salinity of Puget Sound, wind speeds in the subtropical North Pacific, the amount of chlorophyll in the central North Pacific, the salmon catch in Alaska, and the sea surface temperature in the northeastern Pacific. After statistically condensing the values of all 40 variables for each year into a single measure of the environment's deviation from the 16-year mean conditions, the group plotted the deviations over time (see figure). The sudden, stepwise change in 1976 is obvious. Such abruptness is rare in climate-related records.

The immediate cause of the environmental shift around the North Pacific seemed clear enough when Kevin Trenberth of the National Center for Atmospheric Research in Boulder correlated it with meteorological data. Trenberth's analysis showed that the atmospheric circulation of the North Pacific went out of kilter after 1976 and stayed that way until the late 1980s. The low-pressure system that usually hangs over the tip of the Aleutians chain, southwest of Alaska, abruptly intensified, at least during the winter, and shifted eastward toward North America. Both changes meant that the counterclockwise circulation around the low was pumping more warm air northward into Alaska while sending extra cold air southward over the central and western North Pacific. The altered and intensified circulation readily explained two of the shifts seen after 1976—a 1.5°C warming in Alaska and all those big waves on the West Coast.

The changed atmospheric circulation Trenberth traced also seemed to explain more distant manifestations of the 1976 shift. A whole string of regions in which the pressure was alternately higher and lower than normal stretched from Hawaii through the Aleutian low and across North America to the eastern United States. That could explain the modest cooling registered in eastern North America through the mid-1980s as well as those shorter episodes of intense cold that drove up citrus prices.

Tracing the environmental shift to a changed atmospheric circulation, of course, begged the question of what had altered the circulation in the first place. To Trenberth,

Did the Great Salinity Anomaly Cool the Atlantic?

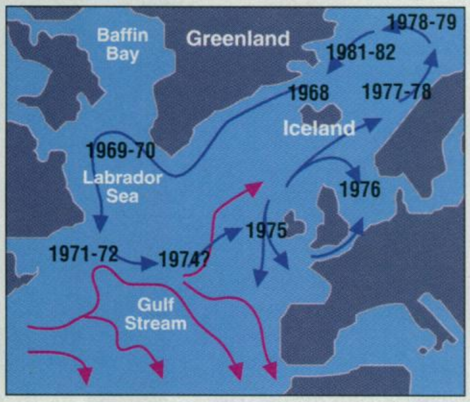
So far, the idea that ocean circulation can change abruptly for a decade or more, unhinging climate over much of the globe, rests on a single instance. That's the recent discovery that the El Niño cycle, which periodically warms the equatorial Pacific, shifted into a new mode throughout the late 1970s and early 1980s, affecting weather from Alaska to Florida (see main text). But another case in point may be waiting in the wings—or, rather, drifting about the North Atlantic. Although the Great Salinity Anomaly, a pool of unusually fresh seawater hundreds of kilometers across, has yet to be convincingly linked to any major climate change, researchers think it might have made nearly as much mischief as the better-studied anomaly in the Pacific.

The Great Salinity Anomaly appeared in the remote, ice-strewn waters of the far North Atlantic in 1968 and spent at least the next 15 years circling the subpolar ocean. For much of that time it went unrecognized. But now it has emerged from obscurity—so much so that oceanographers are wondering whether it may have interfered with the larger system of ocean circulation that carries heat from the tropics to frigid high latitudes. If so, the salinity anomaly may be to blame for bouts of cold weather in Europe and a cooling of the entire Northern Hemisphere. But before the effects, much less the origins, of this shift in ocean behavior can be sorted out, the interaction of ocean and atmosphere over the Atlantic and perhaps the Arctic will have to get the kind of attention that has so far been lavished only on the tropical Pacific.

If a phenomenon only becomes a proper object for study when it gets a name, then the Great Salinity Anomaly came of age in 1988, 20 years late. That was when Robert Dickson of the Fisheries Laboratory in Lowestoft, England, and his colleagues came up with a moniker for a patch of low-salinity surface water whose travels they thought they could make out in oceanographic records. The anomaly—as much as 1.4% less salty than normal and 1° to 2°C colder—first appeared off the east coast of Greenland north of Iceland. Within a year or two currents had whisked it around the southern tip of Greenland into the Labrador Sea. From there it crossed the Atlantic; by the mid-1970s, it headed north into the Norwegian Sea; and it returned to where it had first been spotted by the early 1980s. Since then this odd body of water has, at least temporarily, been lost from sight.

The salinity anomaly is no more than a blip in the grand scheme of the ocean's globe-girdling circulation, but it may have affected a critical process called deep water formation. The subpolar Norwegian, Greenland, and Labrador Seas constitute one of only two regions in the world ocean where extreme cold and a high salt content make surface water dense enough to sink into the deep sea (the other is off Antarctica). The water that flows northward to replace the sinking water carries heat, in part supplied by the Gulf Stream, that warms the climate of Europe.

In principle, the Great Salinity Anomaly could have reduced the density of far-northern surface waters enough to slow the sinking. That would have put the brakes on northward heat flow and cooled the climate. In fact, all three things happened in the 1960s.



Drifting dangerously. *The Great Salinity Anomaly wanders* (blue) *near the currents that warm Europe* (red).

SOURCE: DICKSON ET AL. ILLUSTRATION: D. DEFRANCESCO

Ocean modelers Kirk Bryan and Ron Stouffer of the Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey, have noted that when the anomaly reached the Labrador Sea in the late 1960s, sinking of surface waters ceased for several years and sea surface temperatures across those latitudes dropped. This cooling coincided with a broader North Atlantic cooling and a one-third decrease in the flow of the Gulf Stream and associated warm currents, according to Sydney Levitus of the National Oceanic and Atmospheric Administration.

The expected atmospheric effects were present as well: Europe suffered some harsh winters at the peak of the Atlantic cooling in the late 1960s. And for more than 10 years during the Great Salinity Anomaly's perambulations, the whole Northern Hemisphere cooled sharply.

It may be tempting to finger the Great Salinity Anomaly as the cause of the oceanic cooling and the hemispheric climate change, but oceanographer Arnold Gordon of Columbia University's Lamont-Doherty Geological Observatory urges caution. When dealing with changes in the ocean-atmosphere system spanning a decade or more, he notes, "cause and effect become exceedingly difficult to separate. You don't know what's forcing what."

Causes for the salinity anomaly itself are equally elusive. Dickson and colleagues had suggested that unusually strong northerly winds over the Greenland Sea could have swept in extra polar ice, which melted and formed the pool of fresh water. But recently, meteorologists John Walsh and William Chapman of the University of Illinois found evidence of a more distant impetus for the sea ice movement: stronger-than-normal winds that were blowing all across the Arctic in the late 1960s, as far away as Asia. And in the most ambitious scheme to date, meteorologist Lawrence Mysak of McGill University and his colleagues have combined the salinity anomaly, ocean currents, the weather around the Arctic, and the flux of sea ice out of the Arctic into a 10-link chain of cause and effect. Now that's a theory worthy of a great anomaly. ■ **R.A.K.**

the signs pointed to the equatorial Pacific. The decade-long pattern of altered circulation looked suspiciously like the far-flung atmospheric changes that often result from unusual heating of the eastern Pacific during an El Niño. The difference, of course, is that the pressure and circulation changes linked to an El Niño usually abate after a year or so, whereas the 1976 climate shift persisted year after year.

But this time, Trenberth pointed out, the warming of the El Niño region of the Pacific persisted as well. Three El Niño events warmed the tropical Pacific during the decade after 1976, but the other phase of the cycle—the cooler than normal episodes called La Niñas, which usually alternate with El Niños—was missing until 1988, when a strong La Niña apparently revived the full cycle of warm and cold swings. Until then, the heat never quite dissipated, and the extra heat in the tropics coincided with the regional climate change.

Still, coincidence does not prove causation, especially in meteorology. Now Nicholas Graham has firmed up that link with computer climate models, among them the most sophisticated sort in which the ocean and atmosphere interact on a global scale. By holding ocean temperatures constant except in the tropical Pacific, he was able to explore that area's effect on Northern Hemisphere climate. When he simulated the temperature changes of the tropical Pacific of the 1970s and 1980s, the model produced climate changes much like those seen after 1976. Short of having a dozen cases of such climate shifts to analyze, other researchers say, this sort of modeling is likely to be the strongest evidence available.

That's as far as climatologists have gotten in tracing the chain of cause and effect. Now they are left with a tougher question: What forced the basic change in the tropical Pacific? Speculations are scarce so far, and there's even some dispute about the nature of the post-1976 change itself. While Trenberth stresses the absence of the cold phase of the La Niña-El Niño oscillation, Graham thinks both phases continued, but the thermostat that determines background conditions was somehow reset to a higher temperature. Either way, surfers, citrus growers, and greenhouse policy makers would like to know if and when a shift is likely to happen again. ■ RICHARD A. KERR

ADDITIONAL READING

C. C. Ebbesmeyer *et al.*, "1976 Step in the Pacific Climate: Forty Environmental Changes Between 1968-1975 and 1977-1984," *Proceedings of the Seventh Annual Climate (PACLIM) Workshop*, April 1990 (California Department of Water Resources, 1991).

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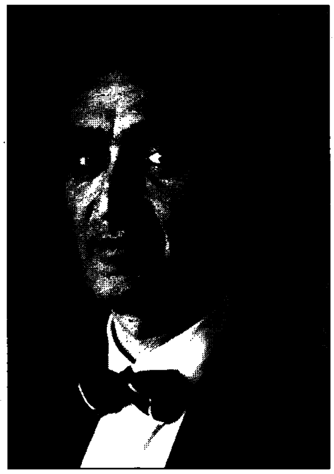
Yeast Biology Enters A Surprising New Phase

Baker's yeast is a well-known model for molecular genetics—but it wasn't quite so well known after all

MANY ANIMALS DON'T BEHAVE IN ZOOS QUITE the way they do in the wild. But the difference between an organism's captive behavior and its behavior in nature isn't limited to lions and tigers. Take *Saccharomyces cerevisiae,* otherwise known as baker's yeast, which in the past decade has become one of the favored model systems of molecular geneticists. While many related molds, such as the human pathogen *Candida albicans*, exist in two phases (a unicellular yeast and a multicellular filamentous phase), switching back and forth between them by an intricate genetic mechanism, *Saccharomyces* was believed to have only the unicellular yeast phase. Until now. In the 20 March issue of *Cell*, Gerald Fink and colleagues at the Whitehead Institute and the Massachusettes Institutes of Technology describe a filamentous phase in *Saccharomyces*.



Taken by surprise. *Gerald Fink at first doubted the evidence for a filamentous phase.*

"*Saccharomyces* had been domesticated by bakers and brewers over hundreds of years and it was thought that it had either lost the capacity to make the switch, or never had it," says Jef Boeke, a yeast geneticist at Johns Hopkins. Because the genetics of *Saccharomyces* have already been intensively studied, the finding could shed some fresh light on gene regulation—and it could ultimately have some clinical implications as well.

The notion of a filamentous phase in domesticated strains of *Saccharomyces* is so surprising that Fink himself says that at first he simply didn't believe the evidence that began to accumulate in his lab. "I thought it was a contaminant—a mold that had fallen in from the ventilation system. If you see it, it doesn't look like our guys," he says. But when graduate student Carlos Gimeno pointed out that the alleged contaminant could mate with the *Saccharomyces* cultures, Fink finally had to concede that they were one and the same.

How is it possible that a major portion of the life cycle has remained undescribed in an organism that is studied in hundreds of labs? The answer seems to be that in most lab cultures all essential nutrients are provided. And, as the new results from Fink's lab show, the filamentous phase in *Saccharomyces* is triggered by starvation.

The Whitehead group discovered this while exploring the environmental growth cues *Saccharomyces* responds to. They were, says Fink, "trying to turn the Petri dish into a facsimile of nature"—something like modern zoos, in which some animals are freed to roam in large open spaces that mimic their natural habitats. But, Fink notes, nature leaves yeasts like *Saccharomyces* in a state of semi-starvation. If it didn't, he explains, they would take over the world: "If you let just one cell divide at its maximal rate, it would form a layer around the earth 10 feet deep after just 2 weeks." Since that doesn't happen, there must be something limiting their growth.

To find out what the limits to growth might be, the group varied the amount of nitrogen in the cells' medium. Eliminating nitrogen completely, Fink notes, puts an end to growth, so they offered the cells reduced amounts of nitrogen. But they weren't quite prepared for what happened to their *Saccharomyces* cultures. Usually, when yeasts replicate, the daughter cell buds off from the parent and eventually forms an independent cell. But in a reduced nitrogen medium, the daughter cell remains attached to the tip of the mother. Then a new cell buds from that daughter's tip, and so forth, until it forms a filamentous chain of connected yeast cells. The *Saccharomyces* chain is actually able to invade the agar on which it grows, which individual yeast cells cannot do.

It is precisely this ability to penetrate agar that leads Fink to speculate that the filamentous phase is *Saccharomyces'* way of foraging for food. "The key thing is that these cells are not motile. So how can an immobile thing get to a new source of food?" he