Tropical updrafts can change climate far to the north and south.

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The Tropics Return to the Climate System

Long neglected by paleoclimatologists, the tropical oceans, and especially the tropical Pacific, are being given their due as participants in and possibly dominant drivers of long-term climate change, from the global warming of the past century to the ice ages of 30,000 years ago

The tropical ocean spent years relegated to the backwaters of paleoclimate research, but it's experiencing a resurgence. Back in the 1970s, a major study of global climate found that the tropical oceans had apparently cooled little in the last ice age while the rest of the world slipped into a deep freeze. Thinking that such climatological inertia implied a minor role in climate change, researchers focused instead on the high latitudes, especially the North Atlantic, as the place where all sorts of long-term climate changes get their start.

But a variety of new paleoclimate indicators is now putting the tropical oceans square in the midst of the climate action. The tropics not only cooled along with the rest of the planet in the last ice age, these new indicators show, but were right in step whenever the world briefly warmed or cooled during glacial times and when the ice age ended. They even seem to have been deeply involved in the warming of the past 50 years. No one has yet fingered the tropics as a prime mover in climate change, but, says glaciologist Richard Alley of Pennsylvania State University, University Park, "when we solve this it's got to involve the tropics."

Until the new data, paleoclimate researchers' cool view of the role of the tropics was based on the Climate Long-Range Investigation, Mapping, and Prediction (CLIMAP) study, published in 1976 in *Science*. In that study, paleoceanographers extracted ocean temperatures from the mix of single-celled animals called foraminifera that lived in surface waters at the peak of the ice age 21,000 years ago. From the proportions of foram skeletons of cold-tolerant and warmth-loving species left in bottom sediments, CLIMAP workers deduced that tropical waters had cooled only about 1°C while the far North Atlantic had chilled 10°C or more.

That reinforced many paleoceanographers' belief that the North Atlantic was much better placed than the tropics to play a pivotal role in climate change. For years, paleoclimate data from around the North Atlantic have pointed to the region as the site of the most dramatic climate shifts, notes Alley. It's near the high-latitude continents where the great ice sheets are born, grow, and decay, and its far northern reaches include the unique and climatically sensitive turning point of the ocean's "conveyor belt." The conveyor consists of surface currents that carry heat from the south to the northern North Atlantic before sinking into the deep sea and turning back southward. With so much going on there and an obvious potential for switching the heat-laden conveyor on and off, the North Atlantic seemed ideal as a prime mover of climate change. As paleoclimatologist Gerald Haug of the Swiss Federal Institute of Technology, Zurich, puts it, the paradigm among paleoceanographers was: "Everything comes from the North Atlantic."

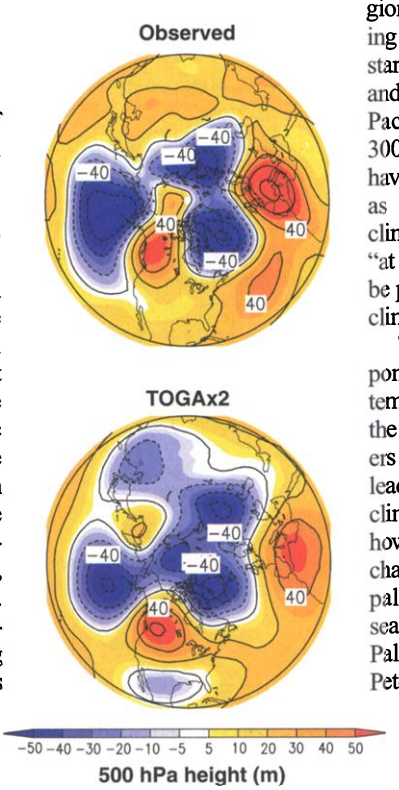
The tropical oceans, it turned out, weren't going to take the North Atlantic hegemony lying down. In the past 5 years, paleoclimate researchers have begun applying new ways of determining past temperatures, from the noble gases dissolved in groundwaters to the altitude of past mountain snowlines. They have also developed a better understanding of forams' temperature preferences. When paleoceanographer Alan Mix of Oregon State University in Corvallis and his colleagues reanalyzed the CLIMAP data in light of this new information, they found a 3°C to 4°C glacial cooling of the equatorial Pacific, not 1°. And when David Lea of the University of California, Santa Barbara, and his colleagues analyzed the chemical composition of skeletons of forams, which substitute magnesium for calcium when the temperature rises, they also found a tropical Pacific cooling of about 3°C. "Clearly, the case is strengthening for cooler glacial tropics," says Alley. "Everyone is drifting in that direction."

For the meteorologically inclined, that's comforting, if expected, news. "Cooling the

rest of the world and not the tropics doesn't make sense," says El Niño modeler Mark Cane of Columbia University's Lamont-Doherty Earth Observatory in Palisades, New York. Meteorologists have long regarded the tropics as the "firebox" of the planetary weather system: the place where the bulk of the solar heat enters to drive day-to-day weather changes in both hemispheres as the heat makes its way toward the poles. It seems only natural that the tropics would be at the heart of changing climate from decade to decade or millennium to millennium as well, says Cane. The North Atlantic, on the other hand, would have a hard time triggering climate change in the other hemisphere, as happened during the last ice age, he says. It faces a barrier in the atmosphere that lets the tropics reach into high latitudes to change atmospheric circulation but blocks a northern influence to the south. In the ocean, a warming in the North Atlantic would simply come at the expense of the Southern Hemisphere.

As the North Atlantic's shortcomings as a driver of global climate change have become obvious, so has the tropical Pacific's potential. "We know when you change things in the tropics, you get global changes," says Cane. "El Niño is one example." And the tropical Pacific could be just as sensitive a climate switch as the North Atlantic, climate modeler Raymond Pierrehumbert of the University of Chicago has pointed out. Whereas the heat-laden conveyor belt is "tippy" where it sinks into the deep sea—its sinking can be turned on or off by a small change in the temperature or salt content of far North Atlantic waters—the tropical Pacific's tippiness lies in its overlying atmospheric convection. Slight changes of surface ocean temperature, as happen when the tropical Pacific swings between the warmth of El Niño and relative cold of La Niña, can determine whether moisture-laden air rises in towering rain clouds. They, in turn, can redirect jet streams in either hemisphere and thus change climate from the Antarctic to far northern Alaska.

That El Niño–like swings in the tropical Pacific could change climate around the world for more than the usual year or two was demonstrated earlier this month in work by meteorologist Martin Hoerling of the National Oceanic and Atmospheric Administration in Boulder, Colorado, and colleagues. In the 6 April issue of *Science* (p. 90), they reported that in their climate model, the warming of the tropical oceans seen in recent decades, especially the tropical Indian and Pacific oceans, can drive the equally gradual shift seen in the climate regime known as the North Atlantic Oscillation (*Science*, 7 February 1997, p. 754). That drift has, in turn, driven much of the warming over the continents that is taken to be the first signs of greenhouse warming. It seems most likely, say Hoerling and colleagues, that increasing greenhouse gases are driving much of global warming by way of the tropics.



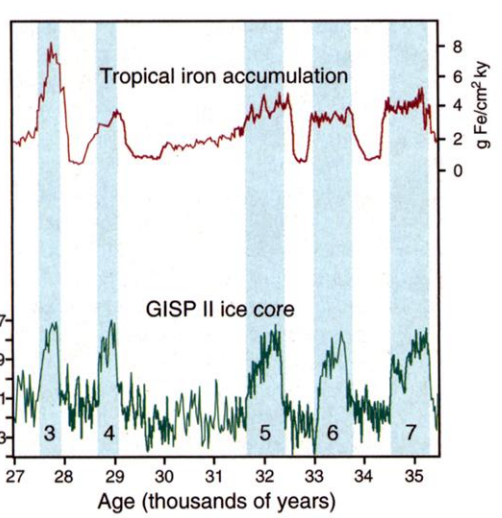
Can-do tropics. Changing only a model's tropical ocean temperatures can change the high-latitude atmosphere (bottom, change in temperature) much as the real atmosphere changed (top).

Farther back in time, in paleoclimate records, modelers have not made a cause-and-effect connection between the tropics and global climate change, but in recent months, groups have reported many examples of tropical ocean climate shifting in time with distant climate. According to analyses of the oxygen isotopes in forams, the pool of warm water in the far western equatorial Pacific that fuels El Niño warmed and cooled in step with millennial-scale warm snaps during glacial periods, as recorded in ice cores in Greenland.

Oxygen isotopes in a cave stalagmite from eastern China reveal that the east Asian monsoon—which draws on the moisture of the western Pacific's warm pool—waxed and waned in time with millennial-scale Greenland climate change during the most recent ice age. And drilling into a former lake bed in the tropical Andes of South America has shown that precipitation there varied on millennial time scales in step with cold glacial episodes in the northern North Atlantic. During the biggest climate shift of all, deglaciation 15,000 years ago, the tropics and other regions actually began warming before the ice in the north started to melt; at Lea's east and west sites in the tropical Pacific, warming started 3000 years ahead. "We don't have evidence for the tropics as *the* driver" of long-term climate change, says Lea, but "at the least, the tropics had to be participating in large-scale climate change."

To pin down any one component of the climate system—such as the tropics—as the dominant driver, researchers would have to catch it leading all other parts into a climate transition and show how it could trigger major change. That's a tall order in paleoclimatology, but researchers are getting a start. Paleoceanographer Larry C. Peterson of the University of Miami and his colleagues recently reported that the amount of rain draining down Venezuelan rivers into the offshore Cariaco Basin increased during warm episodes recorded during the ice age in Greenland ice cores, as judged by the varying amount of iron and titanium washed into the basin. Peterson and his colleagues suggest that the shift to raininess would have pumped more moisture east to west out of the Atlantic, across the low-lying Isthmus of Panama, and into the Pacific. That would have left Atlantic waters saltier, more likely to sink at the end of the conveyor, and therefore able to carry more heat into the north to reinforce the warming.

The Cariaco record may offer a mechanism for a tropical driver of high-latitude climate change, but getting the timing right could be even tougher. El Niño changes climate halfway around the world from one year to the next, while the resolution of most paleoclimate records is still decades at best. "It seems things are coupled at time scales so short, I'm not convinced we'll ever be able to say 'A' caused 'B,' " says paleoceanographer Konrad Hughen of Woods Hole Oceanographic Institution in Massachusetts. "We have a hard time doing that with modern El Niños. The tropics are clearly involved. Are they the sole driver or is something driving them?" –RICHARD A. KERR



CREDITS: (TOP TO BOTTOM) M. HOERLING *ET AL.*; L. PETERSON *ET AL.*

A match. Rains washing iron off South America (top) surged in time with warmings recorded in a Greenland ice core (bottom).