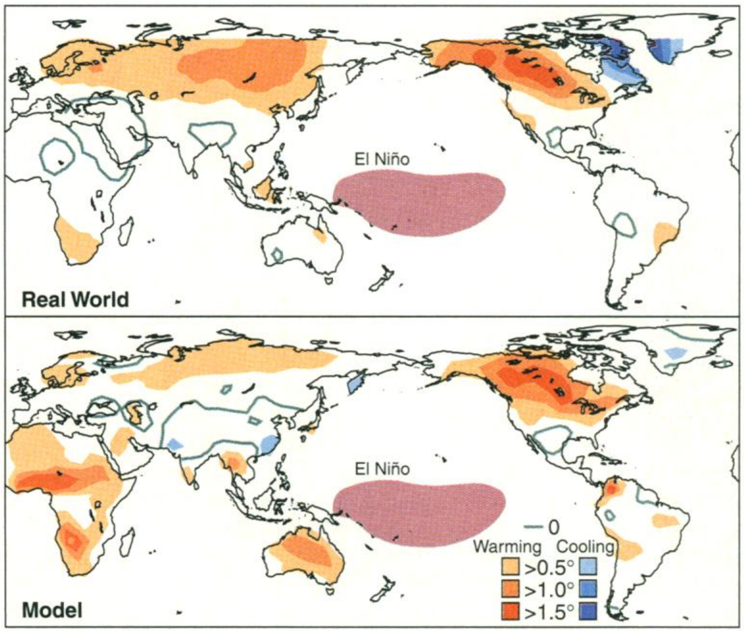
CLIMATE CHANGE

Did the Tropical Pacific Drive The World's Warming?

It looks like things are heating up in the equatorial Pacific. Again. If the warming continues, it would be the third time in 4 years that the weather-altering waters of El Niño have appeared. An El Niño nearly every year or so is hardly normal, but then, it's been quite a while since the tropical Pacific has been "normal"—since 1976, to be exact. The tropical Pacific slipped into its warm mode in the winter of 1976–77 and has never quite shaken it off. Things haven't been the same since—and not just in the equatorial Pacific.



Mimicking climate change. In a computer simulation, unusually warm tropical waters drive long-distance warming that looks much like the warming seen in the real world, especially over North America, in the 1980s.

SOURCE: KUMAR, LEETMAA, AND JI

The persistent warm spell in the ocean, computer climate modelers are finding, may have triggered the global climate shift that brought record-breaking warmth to the globe in the 1980s. Some climate researchers suspect that heat was an early sign of global warming from greenhouse gases. If so, and if the studies by the computer modelers (one of which is reported on page 632 of this issue of *Science*) are correct, the tropical Pacific may be a key link in the mechanism of climate change from one decade to the next. That would be a great boon to researchers struggling to understand climate change, as it would allow them to focus on one small, intensively studied region.

"The tropical [climate] forcing argument is pretty strong," says Daniel Cayan of Scripps Institute of Oceanography, in part because individual El Niños are already known to have widespread climatic repercussions. But the *Science* work, by Arun Kumar, Ants Leetmaa, and Ming Ji of the National Meteorological Center (NMC) in Camp Springs, Maryland—and similar results from other groups—may not be the last word. As Cayan adds, he "would wonder if the tropics explain everything."

Underscoring the uncertainty is a second paper in this issue. Based on a different climate model, it identifies a very different ocean source for interdecadal climate change: a regular oscillation in the winds and currents of the North Pacific Ocean that could be masquerading temporarily as greenhouse warming.

Both proposals are the product of powerful computer simulations. The climate system is so complicated that separating cause from effect is difficult in even the best climate records, and the computer models provide a way out of that tangle by enabling researchers to single out potential causes and test them individually. The NMC group, for example, drove their model of the global atmosphere with several different "oceans"—digital renditions of how global patterns of sea-surface temperature changed over the past four decades—to find out which part of the ocean, if any, was responsible for the warmth of the 1980s.

From the start, the tropical Pacific was the group's prime suspect. Many previous studies had linked individual El Niño warmings to months-long climate shifts around the world, such as unusually warm winters in Alaska, western Canada, and the northern United States. And so it seemed plausible that the longer term warming observed since 1976 might have some connection to the spate of El Niños since then. Since 1976 there have been four—now perhaps five—El Niños and only one major example of the cold episodes called La Niñas, which usually alternate with El Niños. In addition, since 1990 "we're almost locked into a permanent El Niño," says Leetmaa, as unusual warmth lingers in the west-central Pacific between El Niños.

When the NMC group tested the effects of this sea-surface warming in their model, they found that it produced a warming on land in much the same places and at the same seasons as the warming observed in the 1980s, especially over North America. And two other studies published in the past few months, one by Nicholas Graham of Scripps and his colleagues, the other by Ngar-Cheung Lau and Mary Jo Nath of the Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton, New Jersey, have yielded similar results.

Graham and Lau and Nath took a different tack from the NMC group. Rather than driving the model with sea-surface temperatures from the entire world ocean, they tested the effects of individual ocean regions by feeding in data on the temperature changes there while keeping the rest of the ocean unchanged from the long-term average. Both groups found that model runs that included the entire tropical ocean or just the tropical Pacific most closely simulated what happened in the real world, including the 1976–77 climate shift. "At least within the confines of this low-resolution model," says Lau, "the tropical Pacific seems to be the 'pacemaker' for the entire system" at interdecadal time scales.

The Pacific warming probably drove the climate shift in the same way individual El Niños alter distant weather patterns, says Graham: by increasing evaporation at the sea surface. The evaporation in turn boosts tropical humidity and intensifies the release of heat high in the atmosphere as the water vapor condenses into rain. The warming of the tropical atmosphere generates a far-ranging signal that alters distant weather patterns. In keeping with that picture, Graham sees signs in tropical rainfall and humidity records, along with detailed analysis of his own model, that the tropical heat machine did speed up in 1976, when the climate shift began.

But that picture leaves researchers wondering what drove the Pacific warming in the first place. And there Graham sees hints that an enhanced greenhouse effect might be at work. Climate models that include increasing amounts of greenhouse gases, he says, also show an accelerated tropical heat machine. And he notes that it wouldn't be surprising to find the tropics responding more intensively than other regions to greenhouse warming, because their warm waters and atmosphere can rapidly translate any increase in solar radiation into large amounts of water vapor, itself a powerful greenhouse gas.

But the tropical Pacific isn't alone in auditioning for a role as a driver of interdecadal climate change. One of its competitors is the Atlantic Ocean. During the 1960s, shifts in Atlantic circulation may have altered climate in Europe (*Science*, 20 March 1992, p. 1509). And on page 634 of this issue Mojib Latif of the Max Planck Institute for Meteorology in Hamburg, Germany, and Tim P. Barnett of Scripps report that the Pacific outside the tropics can produce years-long temperature shifts over North America without any spur from greenhouse warming.

When Latif and Barnett studied a 100-year run of a Max Planck Institute climate model—a more elaborate simulation that calculates the behavior of both atmosphere and ocean—they found that the model's ocean-atmosphere interaction produces a 20-year oscillation in the sea-surface temperature of the North Pacific. The oscillation appears regardless of what happens in the tropical Pacific—even when that part of the ocean is dropped out of the model.

Latif and Barnett think the oscillation originates in a feedback cycle between the winds that blow across the North Pacific and the huge gyre of ocean currents that circulates around that ocean, bringing warm water from the south. The winds drive the currents, but the strength of the winds in turn depends on the south-north gradient of water temperature. Such feedback loops often generate oscillations; the 20-year cycle length, the researchers say, reflects the great inertia of the gyre. And in a model, the cyclical temperature changes in the North Pacific drive the same changes in land temperatures across North America that El Niño does.

Like the Kumar group's result, Latif and Barnett's has company. Two other climate models, one run for 1000 years of simulated time at GFDL and another for 800 years at Max Planck, also show North Pacific temperatures oscillating with a period of about 20 years. There's also direct evidence that these oscillations take place in nature, Latif says: 50-year records of the strength of the gyre and the behavior of the overlying atmosphere showing that they oscillate more or less in step, on a timetable much like that in the model.

Unimpressed by the observational evidence, Graham argues that the North Pacific Ocean just couldn't muster enough heat to drive the large climate variations seen on land. And since submitting its *Science* paper, the NMC group has tested the role of different parts of the ocean individually. They did find, Leetmaa concedes, that "the high-latitude sea-surface temperatures are in fact responsible for some of the [land] temperature structure at high latitudes," in particular the fit to observations in northern Asia. "But [it's] nothing like what they get. It's about one third of their response."

Other researchers think it's too early to rule out the North Pacific as a driver of interdecadal climate change. As John Wallace of the University of Washington puts it, "We would be remiss to write it all off as being explained by El Niño." But he and his colleagues agree that even if the tropical Pacific isn't the only hot spot of climate change, the trail in this climate mystery has now warmed considerably.

–Richard A. Kerr

Additional Reading

N. E. Graham *et al.*, "On the roles of tropical and midlatitude SSTs in forcing ... interdecadal variability ...," *J. Climate* **7**, 1416 (1994).

N.-C. Lau and M. J. Nath, "... the relative roles of tropical and extratropical SST anomalies ...," *J. Climate* **7**, 1184 (1994).

CONTINENTAL GEOLOGY

German Super-Deep Hole Hits Bottom

It's rare that researchers who find themselves in a hole would like to be even deeper. On 12 October, however, the German continental drilling project known as Tiefbohrprogramm der Bundesrepublik Deutschland (KTB) reluctantly called it quits because of difficult drilling conditions. At a depth of 9.1 kilometers, the hole near Windischeschenbach in Bavaria is a little short of its target depth of 10 kilometers. But scientifically, the bore hole—the world's second deepest in hard basement rock after a 12-kilometer hole in northern Russia—was right on the mark. The new science coming from the $300-million project means "the geology textbooks will have to be rewritten," boasts Peter Kehrer of the KTB staff in Potsdam.

The last kilometer or so of drilling was the hardest slogging, but it seems to have paid dividends as rich as those of the eight above it (*Science*, 16 July 1993, p. 295). One target of the project, a crustal suture formed 320 million years ago when two tectonic plates collided to help form the present Eurasian plate, never did show up. But the abundant brines that had poured into the well at shallower depths continued to flow in at below 8 kilometers, surprising many geophysicists. "You normally think the overburden [of rock] squeezes the cracks closed," says Karl Fuchs of the University of Karlsruhe, "and the hole would become drier [with depth], but it was just the opposite." Because such fluids carry metal-bearing minerals, the finding is altering many geophysicists' picture of ore formation. It also increases the depth at which alteration of rock along fractures can occur.

Potentially the most exciting development from the KTB is still regarded as controversial by some researchers. One goal of the program was to reach the zone where high temperatures and pressures transform rock from a material that fractures under stress to one that flows. The KTB researchers didn't expect to encounter this "brittle-ductile transition," below which normal earthquakes cannot occur, until they reached a depth of 10 kilometers and a temperature of about 300°C. Opinion is divided on whether the KTB hole—at 9.1 kilometers and 280°C—made it into the beginnings of the transition, but Kehrer believes it did. "We wanted to get into that zone, and we did. A lot of things are happening, and we can see them."

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—Peter Kehrer

Others geologists think Kehrer and his colleagues may have been fooled by pockets of soft, hydrated minerals or slippage on fluid-pressurized fractures, which could mimic the ductile rock of the transition zone. But whatever was causing the rock to flow, it helped put a halt to the drilling, because the hole began squeezing shut. Each time the drillers hauled up a worn drill bit and sent down a fresh one, they found that in the meantime the lowest reaches of the hole had shrunk and had to be redrilled—a process so frustrating that Kehrer referred to it as "drilling backward."

Now that the drilling has stopped, scientists will have a better chance to sort out what's actually going on at the bottom of the KTB hole. Future science plans include down-hole experiments such as measurements of stress to see how the crust conveys the forces that shift tectonic plates. Eventually, the scientists will turn the well into a "crustal observatory" to make long-term measurements such as seismic recordings. Then the hole will become a monument to geologists' determination to get themselves into a really deep hole.

–Richard A. Kerr