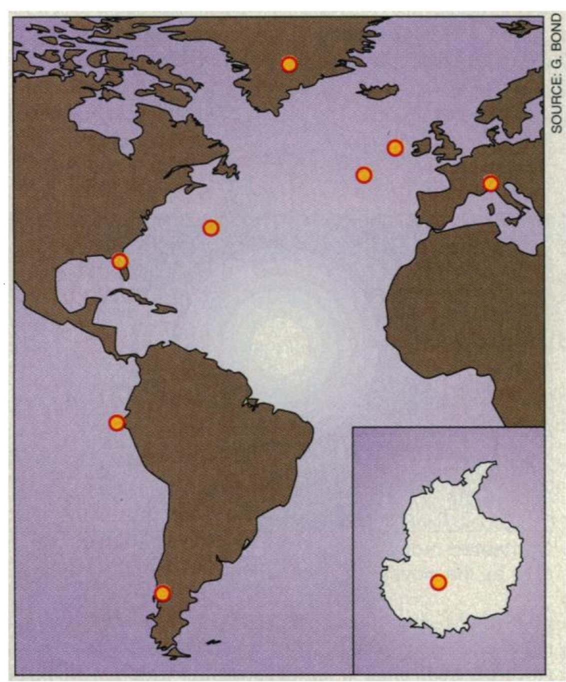
The Whole World Had a Case Of the Ice Age Shivers

For Planet Earth, the past few million years have brought one bad case of the chills after another. And although paleoclimatologists have known for decades that their patient has gotten worse, then better again, every 100,000 years or so as polar ice sheets built up and shrank, new symptoms keep popping up. Just last year, researchers learned that the ice age climate around the North Atlantic had brief bouts of fever, interspersed with cold spells when the planet coughed out huge numbers of icebergs into the North Atlantic. And now it seems that those climate spasms weren't limited to the North Atlantic; they wracked the whole body of the patient, from pole to pole.

At the fall meeting of the American Geophysical Union (AGU) earlier this month, paleoclimatologists heard an array of evidence, from mountain glaciers in South America, ice cores in Antarctica, and sediment cores from the tropical ocean, that leaves little doubt about the diagnosis. But the causative agent remains elusive. To some researchers, the global extent of the climate shivers implies some mechanism for transmitting a climate signal from the ice and ocean currents of the North Atlantic region to the rest of the world. Others are abandoning the North Atlantic as the prime driving force and looking to some shorter-term version of the orbital variations that pace the cycle of ice ages. Most researchers, however, are letting the expanded diagnosis sink in and wondering where to look next to pin down the increasingly complex physiology of the climate system. So far, as Gerard Bond of Columbia University's Lamont-Doherty Earth Observatory puts it, "It's confusion and more confusion."

After all, researchers were already having enough trouble making sense of the North Atlantic records. Two new ice cores drilled in Greenland had confirmed that during the ice age, the regional climate shifted from full glacial conditions to warmer temperatures in rapid swings known as Dansgaard-Oeschger events, lasting hundreds to thousands of years each. These oscillations took place in series, during which their amplitude increased until an exceptionally cold phase gave way abruptly to unusual warmth. Earlier this year, an analysis of sea-floor sediment cores revealed that during the most extreme cold swings, the ice sheet covering much of North America partially collapsed, releasing armadas of icebergs across the Atlantic in so-called Heinrich events (*Science*, 14 May, p. 890).

In the past few months, researchers studying climate records from other parts of the world have realized that these events had some far-flung echoes. Glacial geologist George Denton of the University of Maine, for instance, had been dating the heaps of debris left behind by mountain glaciers in the Andes during their periodic advances. Denton, whose findings were described at the meeting by marine geochemist Wallace Broecker of Lamont, at first didn't see much link between those southern advances—dated at 14,500, 21,000, and 27,500 years ago, along with two more before 36,000 years—and the iceberg armadas in the North Atlantic. The Heinrich events, after all, were thought to have taken place on a different schedule.



A global response. Echoes of the powerful glacial climate signals found in the far northern North Atlantic have been detected at sites from pole to pole.

Last spring, however, when Denton stopped by Lamont on his way home from field work in the Southern Hemisphere, he learned that Bond and his colleagues had revised the timetable of Heinrich events. The new dates: 14,500, 21,000, and 27,000 years ago, along with two events before 36,000 years. The match impressed Denton. And by then he had dated an additional glacial advance to 11,600 years, the same time as a cold snap in the Atlantic region known as the Younger Dryas, which Bond now regards as a Heinrich-like event. Says Denton: "I think it means that the Heinrich events are global climate events."

Strengthening that conclusion is another north-south match reported at the AGU by Todd Sowers of Lamont and Michael Bender of the University of Rhode Island. Dropping their advertised talk, they reported instead on a geochronological tour de force that helped them interpret the Vostok ice core, a climate record cored more than 20 years ago from the Antarctic ice sheet by Russian drillers. Because snowfall is lower in Antarctica than in Greenland, Antarctic ice lacks the annual layering that lets researchers date Greenland cores so precisely. But Sowers and Bender found a way to put Vostok and the climate records from the North Atlantic on a common timescale.

Their strategy was to analyze the isotopes of oxygen from air bubbles trapped in the ice cores. That isotope signal echoes the waxing and waning of ice sheets because the ice tends to lock up water containing the lighter isotope of oxygen, leaving a higher concentration of the heavy isotope in the water and sediments of the oceans and the gaseous oxygen of the atmosphere. Because the isotope signal varies in almost perfect synchrony around the world, Sowers and Bender could use it to match the climate record in the Vostok core with that of the Greenland cores and marine sediments.

When they did the three-way comparison, some previously mysterious wiggles in the temperature record derived from the Vostok ice began to look more meaningful. Nine of them, Sowers and Bender found, matched the Dansgaard-Oeschger events previously recognized only in Greenland ice cores. The bouts of fever that struck the North Atlantic between Heinrich events, it seemed, were also felt half a world away.

The climate shifts may also have been felt around the world as changes in moisture and winds. In the talk right after Sowers,' Jerome Chappellaz of the Laboratory of Glaciology and Geophysics of the Environment in St. Martin d'Hères in France reported that atmospheric methane trapped in a Greenland ice core also varied in step with Dansgaard-Oeschger events. Because most methane is produced in wet, soggy land, Chappellaz concluded that continental aridity—not just the temperature of the far northern Atlantic—must have varied in time with Dansgaard-Oeschger climate events. Still another indicator of global upheaval comes from a sediment core from just off the west coast of South America, in which Bond identified four episodes when increased surface winds boosted marine productivity. These increases, he says, coincide with the four most recent Heinrich events of the North Atlantic.

Just how all these far-flung climate signals—ice sheet collapses, simultaneous warmings and coolings in high northern and southern latitudes, and changes in continental moisture and tropical winds—might be linked is anyone's guess, but paleoclimatologists are willing to speculate. One candidate mechanism dates from when researchers thought the mystery was limited to Dansgaard-Oeschger events in Greenland. Those swings, researchers speculated, could be explained by a climate "master switch" in the currents of the northern North Atlantic. Cold, salty, and therefore dense water sinks into the deep sea at high latitudes, forming a crucial turning point in a globe-girdling "conveyor belt" of currents that bring heat into the North Atlantic via the Gulf Stream. Natural oscillations in the conveyor belt, it seemed, might account for the climate oscillations seen in Greenland.

Another candidate mechanism came to the fore when the Heinrich icebergs showed up: the ice sheet itself. In a scenario proposed by ice-sheet modeler Douglas MacAyeal of the University of Chicago, North America's ice sheet underwent a natural cycle of thickening and collapse. Over thousands of years, it grew until it trapped enough heat flowing up from Earth's interior to melt its base, forming a lubricating layer that caused the ice to slip away in a Heinrich event. The melting icebergs would have put a lid of relatively fresh and therefore less dense water on the far northern Atlantic, temporarily shutting down the conveyor and intensifying the sharp cooling that accompanies Heinrich events.

Some paleoclimatologists think either of those North Atlantic switches might be capable of altering climate worldwide. The conveyor belt itself might carry a North Atlantic climate signal around the globe, notes Scott Lehman of the Woods Hole Oceanographic Institution, because it connects the hemispheres, passing southward through the deep North Atlantic into the South Atlantic and rising near Antarctica. Any variation in the flow of the conveyor—whether the result of an internal oscillation or an ice sheet collapse—could ultimately modulate the amount of sea ice around Antarctica and thus alter southern climate.

Some researchers argue, however, that the trigger for global climate oscillations may lie not in the North Atlantic, but in the tropics. Bond suggested a candidate. Tropical climate, he noted, is especially sensitive to orbital variations, in particular the changing orientation of Earth's axis, which can drive climate change by affecting the distribution of sunlight over the surface of the planet. In the tropics, the cyclical wobble of the axis can produce climate cycles of about 10,000 years. That might explain some of the strongest Dansgaard-Oeschger events, says Bond, and even some Heinrich events, which take place on a schedule of roughly 10,000 years.

But Bond admits that orbital changes are just one possible cause of the global climate spasms. In fact, there may well be multiple, interacting causes for geo-physicians to sort out. The key will be retrieving new records of the patient's past condition in all its far-flung parts.

–Richard A. Kerr

MATERIALS SCIENCE

Wiring for a Very Small World

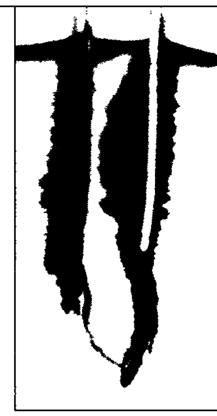
In the world of electronics, sometimes the smaller an advance, the bigger the breakthrough. For example, as circuits for computer chips have become more complex, they have tended to grow in one direction—sideways. Wider chips mean longer processing times and more energy costs, and scientists, looking for complexity without the costs, have been searching for ways to keep circuit size down. One potential solution is to extend that circuit's height, adding another dimension to hold additional circuitry but keep it in a compact form. Now a small step in that direction has been taken by a team from the University of California, San Diego (UCSD), led by chemist Michael Sailor.

On p. 2014 of this issue, Sailor's group describes a chemical process that grows multi-branched molecular wires the size of human hairs, using special conducting polymers that could become complex and compact three-dimensional circuits. This is one of the first fabrication techniques with this potential, says chemist Ralph Nuzzo of the University of Illinois, Urbana-Champaign. "This is still a simple demonstration," says Nuzzo. "But I think it's a really clever idea. It could become very interesting."

The conducting polymer used by the UCSD group is made of organic molecules called 3-methylthiophene (3MT). When monomers of 3MT bond together into a polymer, it can conduct electricity because its electrons are not tightly bound; they can jump from molecule to molecule and carry a current. This also means that the polymer will easily accept or give up electrons and—depending on how many electrons it has at any one time—the polymer can vary from conducting to insulating.

The researchers took advantage of these properties to grow a circuit with little more than some tinkering with an applied voltage. Sailor's group put molecules of 3MT into solution in a beaker and placed a pair of platinum electrodes, with opposite charges, into the solution. A current flowed toward the positive electrode, which began to leach electrons out of the 3MT molecules. These electron-poor molecules then attached themselves to electrons orbiting their neighbors, resulting in shared electrons and tight bonds as the monomers linked up to form a polymer chain. One end of the chain was anchored on the positive electrode, and the other end branched out like a bush as new monomers were added on randomly.

After the chain grew for 30 seconds, the researchers reversed the voltage on the two electrodes. The newly negative electrode began injecting electrons back into the polymer chain, squelching its reactivity and growth. On the other side of the beaker, the newly positive electrode began to grow its own chain. As the voltage shifted back and forth, the two molecular bushes grew toward each other until two of the branches finally met up in the middle. The whole process took 30 to 45 minutes.



RITCHIE

Molecular connector. This polymer wire grew molecule by molecule.

The wire looks more like a molecular tangle, but the connection does conduct electricity. More important, Sailor says, additional platinum electrodes can grow additional wires to come from above and below and join at the initial electrodes. In fact, there should be no limit to how many wires come out of each electrode, allowing the creation of a vast array of multidimensional connections. Such connections could form the basis for a neural network that processes signals much like your brain does, says Sailor, although so far his group has made only a three-sided circuit. "Your brain operates so much better than a computer," says Sailor, "since one neuron can talk to thousands of others, simultaneously."

Before he grows a neural network in a beaker, however, Sailor has a couple of problems to overcome. One is that current now passes through these wires in both directions, and circuits on computer chips require devices with one-directional flow. But if he can solve this and some other minor hurdles, the impact of these little wires could be very big indeed.

–Karen Fox