A North Atlantic Climate Pacemaker For the Centuries

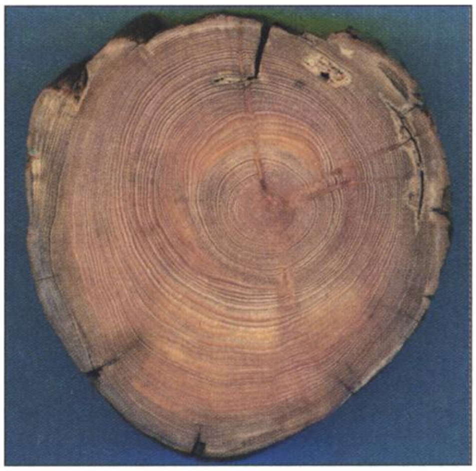
Old trees and supercomputers are revealing a slow, multidecadal climate pulse that beats in the Atlantic Ocean and reaches around the globe

Wiggles are the bane of climate researchers, confusing records of every sort. They're jumbled one atop another on time scales ranging from year-to-year to eon-to-eon. But they can also be a salvation, providing clues to how a single, repeating climate oscillation may be linked to an equally rhythmic cause. Now researchers are picking through the climatic records of recent centuries to track down and explain a squiggle—the first of its kind to emerge—that they hope may clarify variations in the past century's climate and sharpen our ability to recognize greenhouse warming.

The climate swings coming into view don't officially have a name yet, but Atlantic Multidecadal Oscillation or AMO might do. Oscillation because the climate swings one way then the other, multidecadal because they take roughly 60 years to complete an oscillation, and Atlantic because they are most evident in and around the North Atlantic. Most recently, thermometers picked up a swing early in the 20th century from abnormally cold to unusually warm and back. Before that, trees around the Atlantic recorded similar swings in the climate-induced variation of tree ring width that go back several hundred years.

"There's no doubt something is happening in the North Atlantic" during the past 150 years that we've been measuring temperature with instruments, says climatologist Christopher Folland of the Hadley Center for Climate Prediction in Bracknell, United Kingdom. "It's very interesting, very important." Some researchers feel that the AMO might even shed light on the recent rise in global temperatures. "It is possible the enhanced warming in the North Atlantic recently is a superposition of a natural mode plus an anthropogenic mode," says statistical climatologist Michael Mann of the University of Virginia in Charlottesville. Some researchers, especially climate modelers, suspect that oscillations in the heat-carrying currents of the North Atlantic are to blame for this natural mode.

Although the AMO is a new label, what it describes was noticed by climatology's pioneers. Jacob Bjerknes, an originator of the modern concept of El Niño, observed in 1964 that a slow warming of the surface of the North Atlantic in the 1910s and '20s could well have been driven by a surge of warm water up the Gulf Stream. This Atlantic warming accompanied a global warming that by the 1940s had produced the highest global temperatures to that point in the records. It was so warm that statistical techniques used in the 1990s to detect the "fingerprint" of greenhouse warming in climate records also show the 1940s having greenhouse warming, according to work by Gabriele Hegerl of Texas A&M University in College Station and her colleagues. The problem with that analysis is that no one believes enough greenhouse gases had reached the atmosphere by then to cause much of a human-induced warming. That inconsistency has led greenhouse contrarians to complain that any recent warming could just as well be natural rather than anthropogenic.



A tale of the rings. Varying tree ring widths gauge long-ago climate oscillations.

A warm 1940s gave way to a decades-long cooling that set in over the Atlantic as well as the globe. It started talk of the next ice age, or at least the irrelevance of the growing load of greenhouse gases. But Wallace Broecker, a marine geochemist at the Lamont-Doherty Earth Observatory in Palisades, New York, disputed that interpretation and suspected the cooling was just a phase. His 1975 paper in *Science* pointed out that coring of the Greenland ice cap had retrieved a record of two climate oscillations, of 80 and 180 years. In the 1970s, these natural climate variations would have counteracted greenhouse warming fueled by fossil fuel burning, Broecker reasoned, but not for long. "We may be in for a climatic surprise," he warned. Indeed, the North Atlantic soon began warming, the global cooling reversed itself, and temperatures set new record highs in the '80s and '90s.

The existence of as much as two full climatic swings in the last 150 years seems increasingly clear. In a paper soon to be published in *Climate Dynamics*, climate modeler Thomas Delworth of the National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton, New Jersey, and Mann find "overwhelming evidence for a significant multidecadal variation in the climate system during the past 100 to 150 years, centered in the North Atlantic."

This climate variability with a duration of 50 to 70 years—more or less equivalent to the 80-year oscillation seen in Greenland ice—can have some noticeable effects. Winds blowing over a warmer North Atlantic warm the United Kingdom, the rest of Europe, and northern Asia. Delworth and GFDL modeler Thomas Knutson reported recently (*Science*, 24 March, pp. 2126, 2225) that, in one out of five runs of a climate model that simulates the AMO, a North Atlantic–centered warming bore a marked resemblance to the warming of the 1920s and '30s in timing, amplitude, and geographical distribution. "I think [the AMO] played a role in the 1920s–30s warming," says Delworth. On the flip side, meteorologist William Gray of Colorado State University in Fort Collins has linked a colder North Atlantic to the dearth of hurricanes in the '70s and '80s as well as to the drought in the Sahel of northern Africa. He even sees the temperature of the North Atlantic influencing the frequency of El Niños.

Although the North Atlantic may be switching between warm and cold, one or two cycles does not an oscillation make. Meteorological standards call for a half-dozen or more. To go back before the widespread use of thermometers, climatologists have turned to so-called proxy records—the width of a tree ring can reflect the temperature during a growing season; a layer of snow-turned-ice in the middle of the Greenland glacier may record temperature in its oxygen isotopic composition; and a coral growing layer by layer responds to temperature as well. In the past several years, Mann and his colleagues have combined a number of such proxy records into a single record that shows temperature variations around the North Atlantic of several tenths of a degree, with a roughly 70-year oscillation. For comparison, the total global warming from 1860 to the

CREDIT: GORDON JACOBY/LAMONT-DOHERTY EARTH OBSERVATORY present has been about 0.6°C.

Despite the considerable uncertainties inherent in proxy records, "the pattern is significant enough to be clearly detectable," says Mann. "I think there is something going on that is important," agrees modeler John Marshall of the Massachusetts Institute of Technology. And climatologist Yochanan Kushnir of Lamont-Doherty says that, despite all the reservations, climate is oscillating at time scales of a half-century and beyond in a way distinctly different from El Niño or decadal oscillations.

Just what is happening, however, is a matter of ongoing discussion. The proposed AMO has some relation to the North Atlantic Oscillation (NAO) (*Science*, 7 February 1997, p. 754), in which a swinging seesaw of atmospheric pressure with "seats" over Iceland and Lisbon skews climate over and downwind of the North Atlantic. Some meteorologists lump the NAO into a hemisphere-girdling phenomenon called the Arctic Oscillation (*Science*, 9 April 1999, p. 241), but it is still a flibbertigibbet of an oscillation, fluctuating month to month and year to year with little sign of a preference for an oscillation period of 50 years or longer. Such long cycles, most researchers assume, must be paced by the ocean, where massive reservoirs of heat and ponderously slow currents might provide the required slowly ticking clock.

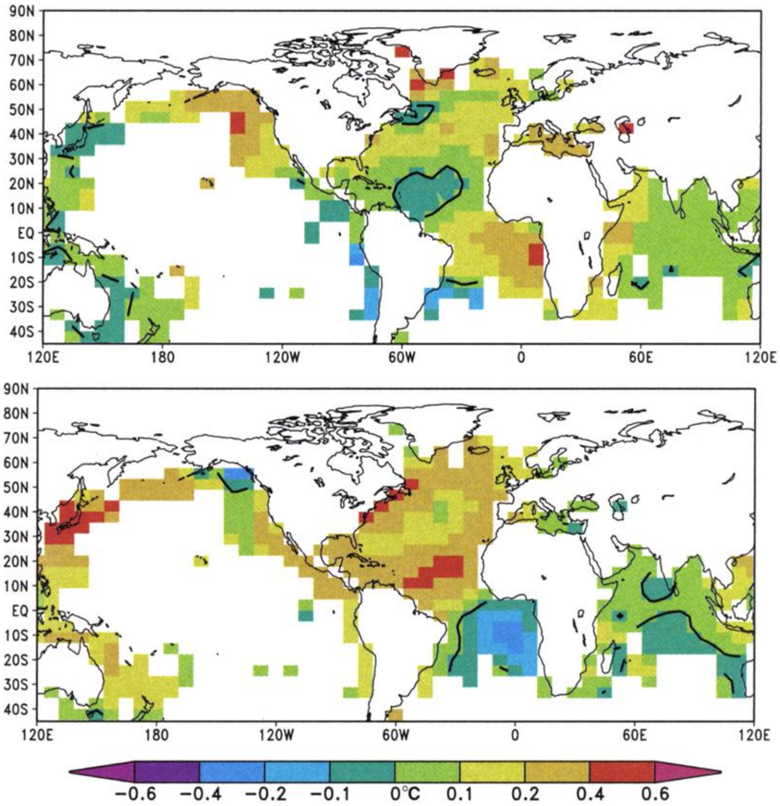
To sort out the ocean's role in multidecadal climate change, researchers turn to climate models. In their forthcoming *Climate Dynamics* paper, Delworth and Mann compare the behavior of a GFDL climate model and the real world as recorded instrumentally and in a 330-year proxy record. "We see a multidecadal mode of variability in the GFDL model," Mann says, "that looks quite like the pattern of multidecadal variability in the proxy record." Both involve Atlantic-wide temperature oscillations rather than the geographically more complex variations of the NAO. The proxies give a period of about 70 years, while the model suggests 50 to 60 years. The difference is negligible, says Delworth, given the approximations used to create any model.

Whereas long-term climate records are limited to Earth's surface, sophisticated climate models use basic physics to build an ocean interior that can be probed for signs of what makes an oscillation tick. In the case of the GFDL model, the AMO seen at the surface reflects a "clock" within the ocean that's "wound" by the atmosphere's NAO. The NAO's seesawing atmospheric pressure alternately cranks up and weakens the cold winds that blow out of the west across the Labrador Sea. The harder they blow, the more heat they extract from surface waters, the denser those waters become, and the easier it becomes for them to sink into the deep sea, drawing more warm water from the south through the Gulf Stream. Thus, in the model, the NAO has a hand on the control valve of the North Atlantic's so-called thermohaline circulation (THC), in which warm water flows north, cools, sinks, and heads back south through the deep sea.

The model's NAO may be able to turn the THC valve, but it is with a most unsteady hand. The NAO oscillates week to week as much as it does year to year or decade to decade, and does so unpredictably. But then, the real and model oceans pay no mind to most of the NAO's jittering. Being slow to change, the model's North Atlantic prefers to respond only to the NAO's longest, multidecadal swings, says Delworth, and then at a pace set by its own ponderous internal works. In particular, the added warmth delivered by an accelerated THC eventually slows other currents that carry particularly salty, and therefore denser, water northward into the regions where sinking occurs. With less salt to encourage sinking, the THC slows, heat transport slows, and the North Atlantic cools. Eventually, cooling will progress far enough to reverse the oscillation by encouraging more salt transport that will enhance sinking and the THC. The THC's inherently sluggish response to the atmosphere's urgings sets the multidecadal pace of the model's AMO.

"The atmosphere is noisy, and the noise drives the ocean beneath it," says modeler Andrew Weaver of the University of Victoria in British Columbia, but only at the more regular pace favored by the ocean. He has also recently found noise acting as a driver in a model, run with Marika Holland of the National Center for Atmospheric Research in Boulder, Colorado, to look at the effect of Arctic sea ice coming into the North Atlantic. "Our work is very similar" to Delworth and Mann's, Weaver says, in that the stream of sea ice out of the north—a major source of fresh, less dense water to the North Atlantic—responds to random variations in the overlying winds. Increased winds in the right direction drive more fresh water into the THC and slow it.

Although some model oceans may be taking their multidecadal cue from the random jostlings of the atmosphere, other models interact with the atmosphere in more of a give-and-take process. Running a global climate model much like Delworth's GFDL model, Axel Timmermann of the Royal Dutch Meteorological Institute in De Bilt and Mojib Latif of the Max Planck Institute for Meteorology in Hamburg found a two-way interaction between ocean and atmosphere that gives rise to a 35-year oscillation centered on the North Atlantic. In their model, surface waters are warmed by an unusually strong THC. The warmth changes salinity not by altering currents but by strengthening the NAO. While this reinforces the warmth, it also gradually causes a reduction in evaporation of fresh water, so salinity drops. Eventually, the declining salinity slows the THC and cools the North Atlantic, which in turn eventually returns higher salinity and accelerates the THC to complete an oscillation. The model even produces an "atmospheric bridge" from the North Atlantic to the



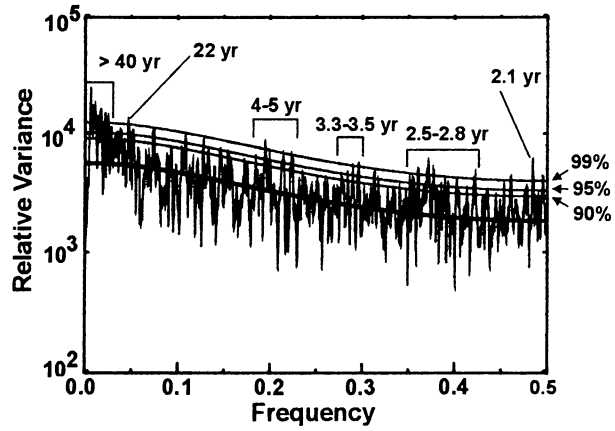
A two-faced ocean. Climate recorded in the width of tree rings suggests the North Atlantic oscillates between a cool phase (*top*) and a warm phase (*bottom*).

CREDIT: T. DELWORTH AND M. MANN

The Sun Again Intrudes on Earth's Decadal Climate Change

Most climatologists have learned to be skeptical about apparent links between the sun's variability and Earth's climate. Again and again, researchers have uncovered plausible correlations, but the evidence usually crumbled under closer scrutiny. And nobody had come up with a convincing mechanism to explain how tiny changes on the sun might change climate on Earth. But suspicious associations between sun and climate keep cropping up. Now, two such correlations—a 22-year climate cycle recorded in glacial sediments and the tracing of an 11-year cycle from the stratosphere into the lower atmosphere—may be robust enough to give the sun-climate link a touch more respectability.

"There's more and more evidence of something pretty distinct at this time scale," says statistical climatologist Michael Mann of the University of Virginia in Charlottesville, a discoverer of the ice age cycle. "I've always been a skeptic" of sun-climate connections, he says, "and I remain a little skeptical, but we can't dismiss it as a statistical anomaly." Paleoceanographer Theodore Moore of the University of Michigan, Ann Arbor, confirmed the 22-year climate cycle in the same glacial record, and he too remains on the skeptical side. "It's hard for me to say where [that cycle] is coming from," he says, but "it's a fertile area for research,"



Small but real. A 22-year climate cyclicity rises above the noise in this analysis of temperature-sensitive sediments.

Geologists Tammy M. Rittenour and Julie Brigham-Grette of the University of Massachusetts, Amherst, and Mann found their 22-year cycle, along with shorter cycles, buried in the layered bottom sediments of now-vanished New England lakes. About 15,000 years ago, sediment-laden waters poured into the lakes from melting glaciers. The warmer a summer's weather, the more ice melted and the more sediment washed into lakes, so the thickness of each annual layer of sediment reflects the temperature during that melt season. Rittenour and her colleagues analyzed 4000 years' worth of layer thicknesses and found statistically significant periodicities falling between cycle lengths of 3 and 5 years. In their 12 May *Science* paper (p. 1039), they attributed those climate fluctuations to the long-range influence of an ancient El Niño. Superimposed on these fluctuations, the researchers identified a 22-year cycle of varying layer thickness.

The 22-year oscillation (actually 22.2 ± 0.2 years), which the researchers described in the same paper, provoked little attention, as it was relegated to a few lines of text and a figure label. But 22 is a significant number to scientists looking for sun-climate links. It's twice the 11-year period at which sunspot abundance and, much less dramatically, solar brightness vary, and it equals the length of the cycle in which the sun flips its magnetic poles back and forth. When an 11- or 22-year periodicity shows up in climate records, suspicion falls on the sun, although it's never been clear exactly how a feeble change in solar brightness or the flipping of the sun's magnetic field would trigger measurable climate change.

"It was a little awkward when we found" the 22-year period, says Mann. "We weren't looking for it. Our immediate guess was that this is from chance sampling variations, that it's a fluke, but we tested its robustness. The thing just holds up. It's a real feature. It's not a dominant signal, but it's always there." Moore doesn't doubt it's there, but he would be very hesitant to say that sunspots are behind any 11- or 22-year climatic periodicity. "I'm cured of that," he says. "We should be very open-minded about what that [periodicity] means." Another, perhaps more palatable, possibility is oscillations inherent in the oceans, he says, that could swing climate to and fro much as one ocean oscillation appears to do on longer, multidecadal time scales of 40 to 80 years (see main text).

The link between sun and climate would be strengthened if, rather than just pointing out solar-like climate periodicities, researchers could demonstrate that their 11- or 22-year climate variations were in step with the variations on the sun. Last year, climate modeler Drew Shindell of NASA's Goddard Institute for Space Studies in New York City and his colleagues showed how, in their model at least, feeble variations of solar output over the 11-year sunspot cycle could gain leverage in the stratosphere and even propagate temperature changes down to the surface (*Science*, 9 April 1999, pp. 234 and 305). Meteorologists Karin Labitzke of the Free University of Berlin and Harry van Loon of the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, had shown that something was letting stratospheric temperatures vary in time with the sunspot cycle, but they hadn't been able to trace solar cycle effects into the underlying troposphere, where weather and climate reside (*Science*, 4 August 1995, p. 633).

Now, van Loon and Dennis Shea of NCAR have crunched the latest set of temperature data since 1958 and found an 11-year variation of several tenths of a degree in the Northern Hemisphere troposphere that was in step with sunspots over four solar cycles. The effect decreases toward the surface when it is averaged around a latitude band spanning the hemisphere, van Loon notes, but he has yet to comb the data for possible effects varying from place to place along latitude bands. Sun-climate effects "is still a topic that's much alive," he says. **–R.A.K.**

North Pacific that entrains the North Pacific in the THC-related 35-year oscillation.

Whatever the role of the atmosphere, the temperature oscillations of the 20th century and the model results have engendered "a strong suspicion that the thermohaline circulation is to blame," says Folland of the Hadley Center. The modeling "is a good step up," adds Timmermann, "but the models must be more mature to say that the thermohaline circulation is involved." A number of models are producing a multidecadal oscillation—within the general range of 35 to 70 years—but such obvious differences as the role of the atmosphere from model to model give pause, says Timmermann.

Still, "we believe more firmly than before that this is real," says Mann of the AMO. "The evidence for this sort of 50- to 70-year oscillation is accumulating in the instrumental observations, proxy climate records, and the climate models." If that is correct, the pace of warming could pick up in the next few decades as a naturally warming North Atlantic combines with a stronger greenhouse warming effect. But it may take a lot more old trees and supercomputing time to calculate how much greenhouse warming will remain the next time the NAO swings to the cool side. **–RICHARD A. KERR**

CREDIT: RITTENOUR *ET AL.*, *SCIENCE* **288**, 1039 (2000)