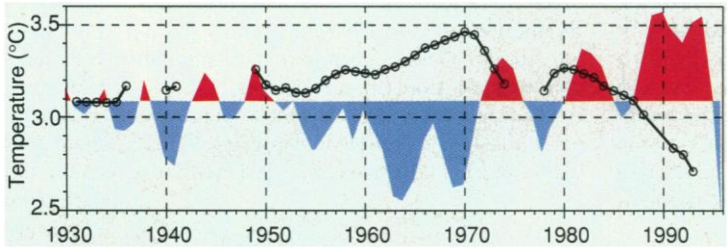
CLIMATE

A New Driver for the Atlantic's Moods and Europe's Weather?

Last November, oceanographer Michael McCartney was enjoying a strangely peaceful voyage across placid waters off southern Greenland. Placid is not the usual word for these latitudes in winter; most of McCartney's previous winter voyages here had met with stormy seas for weeks on end. McCartney already knew part of the reason for this trip's fine weather: Only 1 year before, the atmosphere over the North Atlantic had jumped from the circulation pattern it had favored for 20 years to another mode of operation, which steers storms away from the seas off Greenland. This unheralded atmospheric seesawing—one swing of the so-called North Atlantic Oscillation, or NAO—wasn't entirely benign: While McCartney was savoring calm seas, Europeans were entering their second brutal winter in a row, and skaters in the Netherlands raced long-distance along canals frozen for the first time in a decade.

What drives these decade-long mood swings in North Atlantic wind and weather? McCartney, of the Woods Hole Oceanographic Institution (WHOI) in Massachusetts, and some other oceanographers suspected it wasn't a random whim of the atmosphere but a complex interaction between the ocean and the atmosphere, something like the shorter oscillations in the tropical Pacific Ocean, dubbed El Niño. In higher latitudes, the existence of such an ocean-atmosphere link has never been clear. Now, new data from ocean voyages and new modeling efforts suggest just such a connection.



Current conditions. Temperature in the Labrador Sea Water (circles) has seesawed in time with the North Atlantic Oscillation index, now running low (blue) and bringing cold winter to Europe; the high index (red) means warmer winters.

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Deep within the North Atlantic, McCartney and others are finding parts of a fluid clockwork that may pace the decades-long swings of the NAO of the past century.

If researchers can understand what triggers the NAO switch, they may one day be able to predict it. And they may gain insights into how it may be modulating the warming of the Northern Hemisphere and perhaps even confusing the current search for signals of increasing greenhouse warming (see sidebar). Still, there's a long way to go before oceanographers' studies of the Atlantic catch up with their understanding of the tropical Pacific. McCartney's "suggestions are provocative," says Hugo Bezdek of the Atlantic Oceanographic and Meteorological Laboratory in Miami, one of the oceanographers picking up signs of a link. "There's some evidence to support his ideas, but it will be some time before we can make an ocean-atmosphere connection in the midlatitudes that is robust."

Although the North Atlantic's part of the story is only just coming into view, the atmospheric part of the NAO has long been on display. Typically, low pressure and a counterclockwise wind circulation are centered over Iceland, in contrast to higher pressure and clockwise circulation near the Azores off Portugal. As air swirls around each

A Case of Mistaken Identity?

Two years ago, researchers investigating the suspicious worldwide warming of recent decades concluded that they had glimpsed the culprit's fingerprint. A distinctive geographical pattern of warming pointed to increasing amounts of atmospheric greenhouse gases as the guilty party. As a result, in late 1995, the international scientific community declared that "the balance of evidence suggests that there is a discernible human influence on global climate" (*Science*, 8 December 1995, p. 1565). But is the fingerprint really unique to the greenhouse? Natural agents of climate change, such as the atmosphere's decades-long oscillations in circulation (see main text and *Science*, 28 October 1994, p. 544), may be masquerading as a strengthening greenhouse, according to James Hurrell of the National Center for Atmospheric Research in Boulder, Colorado, and others.

If so, says Hurrell, the recent indictment may have been premature. "It's really important work," says Benjamin Santer of Lawrence Livermore National Laboratory, whose work was pivotal in last year's indictment. "I think it's an issue the [greenhouse] detection community is going to have to get more involved with."

In the 1970s, a pattern of temperature changes began to emerge that recently was shown to match computer predictions of greenhouse warming. As predicted, in winter the land was warming faster than the oceans, which react slowly to temperature change, and the warming was concentrated at high latitudes, where the retreat of ice and snow would reduce the amount of solar energy reflected back to space. But natural-looking circulation changes began appearing at about the same time, notes Hurrell. Low-pressure centers over the Aleutian Islands and Iceland intensified as the atmospheric oscillations there switched to new modes. The resulting changes in circulation pumped more warm, moist air over northern North America and Eurasia while sending more cold Arctic air over the North Pacific and North Atlantic oceans.

The land warms quickly, but the ocean cools slowly. Accordingly, the new circulation produced a net warming centered over the northern continents—a pattern very similar to the greenhouse fingerprint. "The changes in the Aleutian low and the [Icelandic low] explain a lot of the warming in the Northern Hemisphere of the last 2 decades," says Hurrell. He presented his case in *Geophysical Research Letters* last year, and John Wallace and Yuan Zhang of the University of Washington had reached similar conclusions in an earlier study.

These changes can't explain the whole greenhouse fingerprint, such as changes in temperature higher in the atmosphere or in the tropical Pacific. But they do present a "sort of chicken-and-egg problem," says Santer. Are the shifts in circulation entirely natural, or is greenhouse warming driving the changes in the oscillations? Computer modeling may address the issue, but as Hurrell notes, the North Atlantic may soon give its own answer. The atmospheric circulation there swung to the opposite mode about a year ago. If that shift holds, the Northern Hemisphere will cool, he says; if global warming continues apace anyway, the greenhouse will clearly be the prime suspect. Time may tell who left the fingerprint. –R.A.K.

pressure center, strong winds blow west to east across the latitudes in between. The NAO, as meteorologists see it, is a seesaw that modulates this pressure gradient. To start, a bit of extra air mass might pile up over the Azores. Because contrasts in pressure drive winds, this "high-index" extreme of the NAO drives stronger than normal westerly winds, especially during winter when the NAO is most clearly expressed.

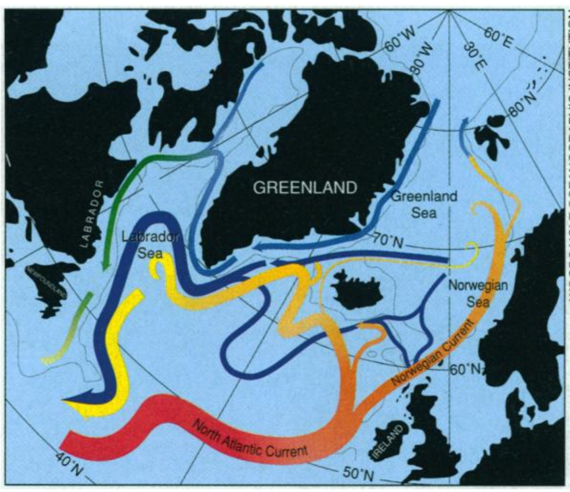
These westerly winds blow over warm Gulf Stream waters as they meander across the northern North Atlantic. The stronger the wind, the more of the Gulf Stream's heat is delivered to Eurasia, so the NAO's high-index years of 1980 to 1995 created unusually mild winters there. But when the NAO swings to the other extreme, as it did with a vengeance late in 1995, air pressure builds up over Iceland, filling in the low and weakening the gradient and warming winds. The effects of a record-low NAO are now on display: a bitter winter in Europe and unusual calm near Greenland.

Although meteorologists could describe the shifts in the NAO over the past century and point to their effects, the origins of the oscillation have largely eluded them. The NAO seesaws on time scales from months to decades, but the atmosphere, with its relatively small mass and rapid response time, "can't 'remember' things year to year or decade to decade, only month to month," says McCartney. So, oceanographers say that the source of long-term oscillations must be in the ocean. Ponderous flows and a huge capacity for storing heat require the ocean to react at a stately pace, providing long-term "memory" as the system operates in the same mode year after year.

McCartney's proposed oceanic oscillator is a vast "pipeline" of warm water fed by the Gulf Stream: the so-called subpolar gyre, a massive, counterclockwise system of currents spanning the ocean off Ireland to the Labrador Sea (see map). All along its route across the Atlantic, past Britain, and back westward by Iceland and the southern tip of Greenland, the pipeline continually loses its heat to the atmosphere and so moderates Europe's climate. By the time it nears completion of the loop, pipeline water is so cold and therefore dense that a single winter's chill in the Labrador Sea is enough to send it plunging beneath the surface, sliding southward out the end of the pipeline.

All told, this trip takes about 20 years, says McCartney, just the kind of timing needed for the NAO's long-term swings. To work as an NAO pacemaker, however, the pipeline would need two other working components: a means of driving the atmosphere into NAO-like modes and a way for the timer to switch between modes.

Now, new oceanographic data suggest just such a potential driver, in the form of unusually warm or cold masses of water running through the pipeline. In work published last year in the *Journal of Geophysical Research*, Donald Hansen of the University of Miami and Bezdek compiled sea surface temperatures of the wintertime North Atlantic since 1949. In the records, they were able to trace a huge patch of anomalously warm water that appeared in the earliest 1950s. They followed it from the Gulf Stream to Newfoundland and across the Atlantic; by the late 1960s, the warm water had made a circuit of the subpolar gyre, following the pipeline around to the Labrador Sea. In the late 1960s, a cold patch of surface water appeared in the subtropics and followed a similar path. And in work they discussed at December's meeting of the American Geophysical Union, McCartney and Ruth Curry of WHOI took a deeper look at these anomalous masses. They used temperatures measured at a depth of 400 meters by instruments lowered from ships to show that Hansen and Bezdek's warm and cold patches are not just wimpy surface skins but are thick enough to deliver a thermal punch to the atmosphere.



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An oceanic roundabout. As warm ocean currents in the subpolar gyre gradually cool (red to yellow trend), they warm Europe and may help trigger seesaws in climate.

The timing suggests that's just what they did, says McCartney. Throughout recent decades, the pipeline and the oscillation have stayed in step, although the relation might seem counterintuitive at first. As the pipeline ran warmer in the 1950s and '60s, the NAO grew progressively more negative, with weaker westerlies across the Atlantic. As the westerlies weakened, so did their influence on Europe, until more northerly winds out of the Arctic replaced them, and colder winter weather settled into Europe; when the pipeline ran cold in the next 2 decades, the NAO switched and became more and more positive. That's not so surprising, says McCartney; the crucial factor for the strength of the NAO—and for Europe's weather—is the strength and the direction of the westerlies, not the warmth of the ocean water.

Just how the pipeline running hot or cold could have tipped the oscillation isn't clear, McCartney admits: "There's a burden on the modelers to confirm or deny within the physics of the system whether [a connection] exists." That may take a while, he adds, given the difficulty modelers have had in realistically linking ocean and atmosphere.

If the pipeline's temperature does determine the NAO's state, what might trigger the temperature switch in the ocean? A deep-ocean mechanism proposed in the *Journal of Physical Oceanography* late last year by Michael Spall of WHOI might offer an answer. After the chilled water exits the pipeline in the Labrador Sea, it hugs the deep edge of North America, where it must eventually pass beneath the shallower Gulf Stream. But that's no small task, notes McCartney. In his model of western North Atlantic currents, Spall found that this Deep Western Boundary Current (DWBC) can either be caught up by the Gulf Stream and swept offshore, strengthening the Gulf Stream in the process, or continue southward unimpeded.

This duel of currents creates a valve at the beginning of the pipeline whose position—wide open or throttled down—depends in part on the thickness of the DWBC. And that raises the possibility of a 20-year feedback loop, says McCartney. A warm signal sent down the pipeline as the Gulf Stream strengthens could 20 years later make the DWBC a bit thinner and so weaken the Gulf Stream. That cold signal might then come back another 20 years later to complete the cycle.

If all this is not just plausible, but also true, then by carefully charting conditions in the Gulf Stream, DWBC, and deep North Atlantic, researchers could perhaps one day predict the North Atlantic's moods—and forecast severe winters for Europe years in advance. But at this early stage, most of McCartney's colleagues are quite cautious. Meteorologist Timothy Palmer of the European Center for Medium-Range Weather Forecasts in Reading, England, notes that it isn't clear yet that the ocean's behavior drags the atmosphere along with it. The atmosphere may still be far less predictable than in El Niño, he warns. "I want to believe" that the North Atlantic strongly affects the circulation of the atmosphere, says Bezdek, "but I don't think a concrete case has been made yet. There's evidence for [an ocean-atmosphere] connection, but it's not overwhelming." To win the day, oceanographers will need many more trips to sea, regardless of whether the NAO is calming the waters.

–Richard A. Kerr