ATMOSPHERE

A New Force in High-Latitude Climate

The Arctic Oscillation is vying to be seen as the prime mover of high-latitude climate shifts, and may even be an agent of greenhouse-induced warming

El Niño, the periodic warming of the tropical Pacific that roils rainfall patterns from Indonesia to Brazil and the Horn of Africa, is the undisputed king of climate shifts. But although El Niño's reach extends to latitudes as high as North America, some researchers are concluding that an oscillation of another sort holds sway over climate in high-latitude parts of the globe.

According to new analyses by a pair of meteorologists, an erratic atmospheric seesaw, which alternately raises pressures over the pole and in a ring passing over southern Alaska and central Europe, is the master switch for climate over high northern latitudes. When this Arctic Oscillation, or AO, is in its so-called positive phase, pressure drops over the polar cap and rises in high latitudes around 55 degrees, which in turn strengthens westerly winds there. Ocean storms steer more northerly, wetting Scandinavia and Alaska, for example, and drying Spain and California. Ocean warmth blows into Eurasia, thawing Moscow. After weeks or years, the AO flips to the opposite phase, reversing these climate extremes—wetting Spain and chilling Moscow.

Meteorologists David Thompson and John M. Wallace of the University of Washington, Seattle, think the AO is a natural atmospheric response that can change minor perturbations into major climate shifts. Researchers are still analyzing many possible triggers for the AO, but whatever its cause, understanding it is "going to help make sense out of" high-latitude climate variability, says Wallace. The pressure oscillation has largely been stuck in the same phase for decades, for example, and may be responsible for an ominous warming trend in the high-latitude Northern Hemisphere that has been viewed as a sign of human-induced warming.

Thompson and Wallace add that the AO also seems to encompass a smaller scale oscillation already recognized as the reigning climate maker in the North Atlantic region: the North Atlantic Oscillation or NAO, a seesaw of atmospheric pressure between Iceland and Lisbon (*Science*, 7 February 1997, p. 754) that skews climate near the North Atlantic but not the North Pacific. "The NAO is just a regional manifestation of the AO," says Thompson. Wallace calls recognition of the AO "a paradigm shift in the way we think."

Some other atmospheric scientists agree that he and Wallace are onto something big. "This AO is a significant mode of variability," says meteorologist David Karoly of Monash University in Clayton, Australia. But others point to uncertainties in the data and suggest that Thompson and Wallace are just seeing the effects of the NAO, whose climatic impact is largely limited to the North Atlantic and northern Eurasia. "I think the AO and the NAO are largely the same thing," says meteorologist James Hurrell of the National Center for Atmospheric Research (NCAR) in Boulder, Colorado.

Icebreaker. The Arctic Oscillation may be behind the melting found by the Arctic mission SHEBA last year.

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The AO, if it's real, has a counterpart in the Southern Hemisphere, which is why Thompson and Wallace went looking for it in the first place. In the Southern Hemisphere, westerly winds in the troposphere—the lowermost 10 kilometers or so of atmosphere—form a complete ring around a latitude of about 55°, as do the overlying stratospheric winds. Atmospheric pressure in the polar region and in the encircling ring rises and falls in a seesaw fashion, and this pressure difference in turn causes the winds to oscillate in strength. A stratospheric vortex swirls all the way around the North Pole too, but there was no such obvious ring in the troposphere, only the NAO's north-south pressure seesaw over the Atlantic.

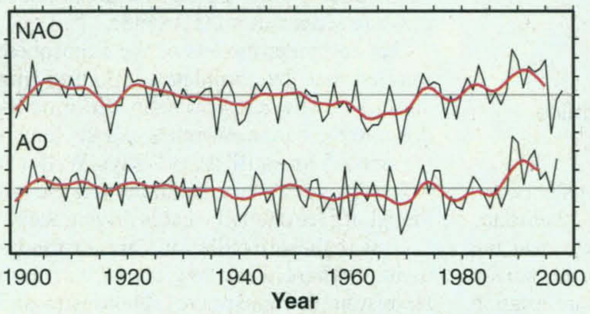
Yet computer models of the atmosphere implied that the complete oscillating ring should be there. "You strip the models down to the barest essentials and the [annular winds] are still there," says Wallace. "They're very, very fundamental," even though it's hard to tell what is driving them.

But if these oscillations are so fundamental, where were they in the Northern Hemisphere troposphere? Thompson and Wallace sought them in the latest, most complete compilation of weather data from weather stations and balloons from 1900 to 1997. From the surface to the top of the troposphere, they found the seesaw pattern of the NAO. And for the first time, they also found another part of the ring: The troposphere over the northern North Pacific pulsed in time with that over the North Atlantic, so that the climate of both places varied in synch. Parts of the ring over land masses are still missing, but Thompson and Wallace put that down to obstacles like the Rocky Mountains and the Tibetan Plateau and to temperature contrasts between land and sea that can disrupt weather patterns. In a paper published in *Geophysical Research Letters* last year, they dubbed the pattern the Arctic Oscillation.

According to Thompson and Wallace's analysis, the AO explains northern climate better than the NAO alone. When the high-latitude tropospheric winds of the AO are strong, they blow the ocean's warmth onto the continents, moderating winter chill in northern Canada and Eurasia; weaker winds let the continents cool. Over 30 winters, Thompson and Wallace found that the AO's varying winds accounted for 42% of Eurasian wintertime temperature variation, while the NAO's explained only 32%. And in a paper in press in the *Journal of Climate*, Thompson and Wallace detail the AO's strong resemblance to the long-studied southern annular oscillation, which they now call the Antarctic Oscillation or AAO. In both hemispheres, they found, when the pressure over the poles falls, high-latitude westerlies strengthen, high latitudes are unusually warm, the polar caps are cold aloft, and the stratospheric vortex intensifies; as a side effect, the stratospheric cold helps destroy ozone in the springtime, deepening polar ozone losses.

Reaction to the AO's debut has been mixed. "I think it's real," says climate modeler Ngar-Cheung Lau of the Geophysical

Fluid Dynamics Laboratory at Princeton University. Thompson and Wallace "are fairly convincing that there's something there," agrees meteorologist Brian Hoskins of the University of Reading in England. Others are more cautious. Meteorologist Clara Deser of NCAR isn't sure that the AO is different from the NAO. In particular, she is not sure that the Pacific and Atlantic are connected tightly enough to warrant lumping their variability together.



Something's up. Both the AO and NAO indices have been on the rise, perhaps fueled by global change.

If the AO does rule high-latitude climate, it may be behind the dramatic Northern Hemisphere warming trend over recent decades. For the past 30 years, the northern oscillation has drifted into a "positive phase," so that while pressure continues to rise and fall, it is almost always below normal over the polar region, subpolar westerlies are stronger than normal, and high-latitude land is warmer than normal. The wind shifts also tend to open more breaks in Arctic Ocean ice. If the trend continues, says Wallace, in a few decades "we may be on the verge of an ice-free Arctic Ocean in the summer." In a second paper in press at the *Journal of Climate*, Thompson and Wallace calculate the amount of warming expected from these changes in wind patterns. They conclude that the AO trend can account for about half of the winter warming observed over Eurasia during the past 30 years and about 30% of the winter warming seen over the whole Northern Hemisphere.

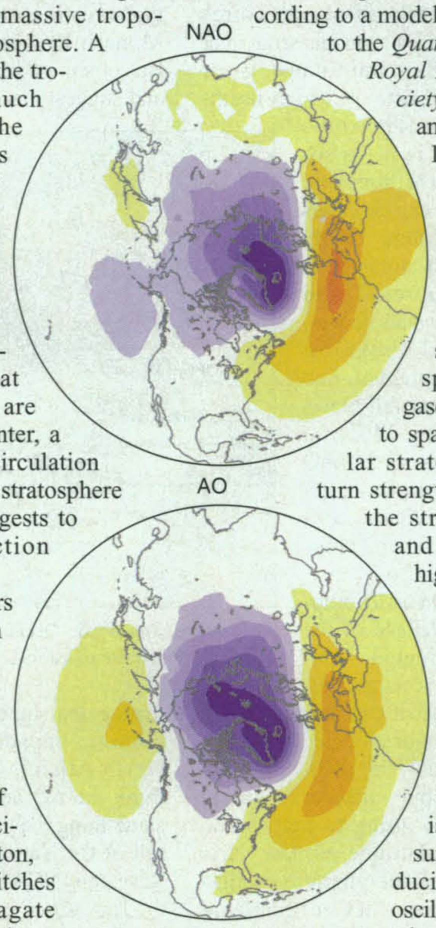
It was this very warming, particularly over northern land areas, that helped convince an international panel of scientists, the Intergovernmental Panel on Climate Change (IPCC), that the first glimmer of greenhouse warming had been spotted (*Science*, 8 December 1995, p. 1565). The link to the AO doesn't necessarily negate the greenhouse connection; greenhouse advocates could argue that the intensifying greenhouse is tipping the AO, notes Karoly, who is a co-leader in the next IPCC report due in late 2000. A computer modeling study by John Fyfe and his colleagues at the Canadian Center for Climate Modeling and Analysis in Victoria supports that possibility. In their model, described in an upcoming issue of *Geophysical Research Letters*, increasing greenhouse gases triggered a positive trend in the AO.

But, as Karoly points out, a greenhouse skeptic could say that much of the observed warming is simply part of a natural AO cycle that will soon reverse. Deciding who's right will require a reversal of the AO trend—something a natural trend but not an anthropogenic one could do—or a better understanding of what drives the AO.

Researchers are beginning to suspect that many of the possible triggers originate in the stratosphere. That's a startling idea, because meteorologists have traditionally assumed that the connection goes the other way, from the massive troposphere to the wispy stratosphere. A stratospheric influence on the troposphere seemed too much like "the tail wagging the dog." Only powerful forces in the lower atmosphere or at the surface, such as El Niño's ocean warming or the ocean changes implicated in the NAO, seemed capable of roiling the troposphere. Still, some researchers had noticed that the northern oscillations are several times larger in winter, a time when stratospheric circulation favors a link between the stratosphere and troposphere. That suggests to them that this connection strengthens the oscillation.

And a study of 40 years of weather data from throughout the atmosphere, submitted to the *Journal of Geophysical Research* by meteorologists Mark Baldwin and Timothy Dunkerton of Northwest Research Associates in Bellevue, Washington, shows that short-term switches in the AO tend to propagate from the upper stratosphere downward to the surface. The change beefs up or weakens the stratospheric vortex, spreads to the troposphere, and shifts storm tracks across the North Atlantic. With about 3 weeks required for the trip from upper stratosphere to the surface on average, forecasters might conceivably have a chance to predict shifts in storminess, precipitation, and temperature across Europe, says Dunkerton.

But no one knows which factors in the stratosphere might be calling the tune long-term, and there are a number of possibilities. Volcanoes are one: In recent years, both observations and modeling have suggested that stratospheric debris from the eruptions of El Chichón and Mount Pinatubo triggered warm winters in the high latitudes (*Science*, 28 May 1993, p. 1232), just as the AO can. And in this issue of *Science* (see News story and p. 305), researchers report that in a computer model, subtle variations in the sun's brightness accompanying the 11-year sunspot cycle trigger swings in stratospheric and even tropospheric circulation; during the solar maximum, the resulting pattern resembles a positive AO, warming Northern Hemisphere high latitudes in the winter. Loss of stratospheric ozone can also drive a long-term trend in the AO, according to a modeling paper submitted to the *Quarterly Journal of the Royal Meteorological Society* by E. M. Volodin and V. Ya. Galin of the Institute of Numerical Mathematics in Moscow. And greenhouse gases also may be behind the trend, as they too affect the stratosphere. Stratospheric greenhouse gases radiate more heat to space, cooling the polar stratosphere, which in turn strengthens the winds of the stratospheric vortex and eventually warms high latitudes.



Completing the ring. The NAO (*top*), a seesaw of atmospheric pressure between blue and yellow areas, may be part of the larger AO (*above*).

Of course, other, slightly different models don't produce an AO trend with such forcings. Because not everyone believes that the AO actually exists, perhaps it's not surprising that reproducing the trend in the oscillation "is still somewhat model-dependent," as Lau puts it. It will take models that consistently produce an AO trend through an understandable mechanism—and confirmation of the AO's existence by independent analyses of weather data—before this oscillation can be crowned as the climate maker of the north.

–RICHARD A. KERR

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