Research News

Capturing El Niño in Models

The physical mechanism that makes a model produce El Niños is an oscillator in the tropical Pacific; whether the models and reality coincide remains unclear

If El Niños really work the way the latest mathematical models of them do, each warming of the tropical Pacific Ocean may sow the seeds of its own destruction. But in the models an internal clock, set ticking by the warming and paced by the behavior of some odd ocean waves, stretches out the cycle long enough to produce the several-year spacing typical of El Niño events. Thus, the oscillator that drives the El Niño cycle, at least in the models, resides within the tropical Pacific Ocean.

This new insight, prompted in part by last year's apparently successful prediction by several models of the current El Niño, has researchers excited. Until now, they had been dissecting past events in search of a common denominator. The result was about as many theories as theorists and no luck in predicting imminent events. "Until now an El Niño has been like a magic trick," says John Wallace of the University of Washington. "Now we at least have the groundwork to understand predictive models. We're back to doing science."

The problem was that although Jacob Bjerknes had pointed out 20 years ago why there might be either abnormally warm or abnormally cold water in the central and eastern equatorial Pacific, no one could explain why conditions should shift from one to the other. Both the warm El Niño and the cold, so-called anti–El Niño sustain themselves through the winds that blow into areas of warm air rising over warm ocean water. During an anti–El Niño, winds blow from the east toward warmer water in the western Pacific. That tends to pile warm water in the west and draw deeper, colder water to the surface in the east, accentuating the temperature contrast that drives the wind. The stronger the temperature contrast, the stronger the wind that strengthens that contrast.

A similar positive feedback reinforces the warm conditions of an El Niño. Then, unusually warm water extends into the eastern Pacific, accompanied by winds that blow from the west into the rising air over the warm water. That drives the ocean into a pile, cutting off the upwelling of deeper, cold water. The more the wind blows, the warmer the water becomes, and the stronger the wind gets. So, what would break the ocean-atmosphere system out of such entrenched conditions? Why not a perpetual El Niño or anti–El Niño instead of swings from one to the other? And in particular, why switch every 3 to 4 years?

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The answer to both questions is found in the ocean, at least in the current models that couple the behavior of the ocean to that of the atmosphere. It turns out that the westerly winds of an El Niño that raise sea level in the east must at the same time send a signal to the west that lowers sea level. That signal is in the form of a Rossby wave that moves just off the equator at a leisurely 25 to 85 kilometers per day and only from east to west. Taking months for a single wave of depressed sea level and varying currents to pass, Rossby waves march to the western boundary of the Pacific basin. In the models the western boundary is a nice hard, smooth wall but in reality it consists of quite irregular island chains such as the Philippines and Indonesia.

On reflection at the western boundary of the models, Rossby waves become coastal Kelvin waves carrying the same negative sea level signal. They shoot toward the equator, whether they hit north or south of it, and then head to the east, but not the west, along the equator at about 250 kilometers per day. When enough Kelvin waves of sufficient amplitude arrive from the western Pacific, their negative sea level signal can overcome the feedback tending to raise sea level and drive the system into the opposite cold mode. But the accompanying wind shift sends positive Rossby waves westward that will eventually return as cycle-ending Kelvin waves and another warming will begin.

"That is the essence of the thing," says Mark Cane, who with his colleague Stephen Zebiak at the Lamont-Doherty Geological Observatory made the earliest forecast of this El Niño. "I prefer to think of it in terms of water exchange, but it's perhaps clearer to say that at the same time that a positive signal is being sent eastward, a negative signal is going westward. The seeds of the next phase are being sown by this one."

This internal oscillator that pushes the model's atmosphere-ocean system from one extreme to the other and back would not work at all if Earth did not rotate. Both Rossby waves and Kelvin waves owe their unidirectional motion on or near the equator to the Coriolis effect, the tendency of any moving object to turn to the right in the Northern Hemisphere and to the left in the Southern Hemisphere. Earth's rotation provides an essential asymmetry, notes Cane. "On a rotating sphere, the ocean knows which way north is," and thus the difference between east and west.

Something of a consensus is begining to develop among modelers that they are onto a good thing. "What is going on in Cane and Zebiak's model is very much like what is happening in ours," says Max Suarez of the Goddard Space Flight Center in Greenbelt, Maryland. "Ocean wave dynamics on the equator is critical" to understanding the model El Niños, he says. He and Paul Schopf are running a coupled model that is more sophisticated than that of Cane and Zebiak in that it predicts climate itself rather than departures from normal climate.

David Battisti of the University of Washington has been analyzing his own version of Cane and Zebiak's model with Anthony Hirst. They too explain the basic behavior of their model in terms of Rossby waves reflecting as Kelvin waves. "We're most surprised," says Hirst, "that our conclusions are so close to those of Schopf and Suarez."

George Philander of the Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey, is running the most sophisticated El Niño model, coupled general circulation models (GCMs) of the atmosphere and ocean. Such models of the atmosphere include sufficiently detailed physical processes for the forecasting of daily weather. At this level of sophistication, it is still the ocean and its equatorial waves that drive the cycle and set its time scale, says Philander. Even if the model's cycle of changing seasons is surpressed, the same kind of El Niños appear at similar intervals. The seasonal cycle had been suggested as an external clock to set the timing of El Niños.

Modelers do have their reservations, mostly about how closely their computer simulations mimic the real world. One problem area is the Pacific's western boundary. Wave reflection from it is clearly vital to the models; remove the western boundary and the El Niño cycle disappears. But the real boundary might be such a poor reflector that the Rossby waves would simply pass through it. Cane sees evidence that even a moderately weak reflector would suffice. Others are not at all sure.

Another problem is the interval between El Niños. In nature it is 3 to 4 years, in the models it is about 2 to 4 years, but a single round trip for equatorial waves is little more than a year. This discrepancy might be resolved if the real mechanism is more complicated than a single round trip. Suarez and Schopf are pursuing the possibility of a second round trip begun in mid-Pacific by reemission of Rossby waves.

A debate that does not bear on the models' basic validity concerns the variability of the El Niño cycle. In the simplest versions of the models—no seasons and no weather—the cycle is like clockwork, quite periodic. In the most complex version, Philander's coupled GCMs, the cycle ranges from fairly periodic to rather irregular, much as is observed. From work with his own model, Cane believes that the addition of as little variability as contained in the seasonal cycle can produce the needed variability in the El Niño cycle. On the other hand, both Suarez and Philander find that in their own models random weather events, such as the intrusion of mid-latitude storms, increase the variability of otherwise periodic cycles. "The basic thing going on is periodic," says Suarez, "but the cycling is being pushed around by all the noise" in the atmosphere.

All the modelers will be tinkering with their own models, but they are also anxious to see more coupled ocean-atmosphere GCMs run in order to decipher just how the models are doing what they do and how that behavior relates to the real world. That will take time. A coupled GCM model takes perhaps 40 seconds to simulate 1 day of model time on a supercomputer, and many decades of model time will be required. ■

RICHARD A. KERR

El Niño and Winter Weather

The National Weather Service's (NWS's) long-range weather forecasters have just issued their winter outlook for the nation: warmer and drier than normal in the Southwest, wetter than normal along much of the Gulf Coast and the East Coast, and a mixed bag for the east-central states.

An early step to such a forecast is deciding whether an El Niño will be around to exert its global influence on the weather. Last fall, the recognition by climate researchers of an emerging El Niño helped the forecasters boost the accuracy of their precipitation forecast. This year they declined to take a chance on El Niño forecasting. Last winter's warming of equatorial Pacific waters persisted into this fall and threatened to carry through the winter, but, according to Donald Gilman, the NWS's chief long-range forecaster, "We only decided that we didn't know what it would do, so we thought we'd better not act as if we did."

That might be a prudent course considering the recent track record for predicting El Niño behavior. Several computer models predicted that the current event would begin in the summer and early fall of 1986. Other experts, and by June 1986 even some of the modelers, thought the models would soon be proved wrong. They were not. By January, there was general but not complete agreement that the event would wind down by spring. It did not. In June 1987, opinion favored an end to it within months, but it is still there. The water is nearly as warm as ever, but the pattern of the winds sustaining the warm water has changed during the past month or two.

Among those contacted by *Science*, opinion marginally favors persistence of warmer than normal waters into February, if only because of the phenomenon's inertia. "Maybe we are at the peak," says Ants Leetmaa of the NWS Climate Analysis Center, "but it will be some months before it is back to normal. There's so much warm water out there."

Divining the state of this winter's tropical Pacific from last week's or last month's observations is not a profitable approach, says Leetmaa. "What we've learned from following things week by week is that trends cannot be determined on a weekly basis, or even on a monthly basis." That note of caution was recently reinforced by Clara Deser and John Wallace of the University of Washington. They inspected the record between 1925 and 1986 of coastal South America sea surface temperature (the gauge of a classic El Niño), central Pacific sea surface temperature (the source of global weather effects), and the basin-wide seesaw of atmospheric pressure. Unlike the canonical, composite El Niño drawn from the 1950–1976 record, which has two coastal warmings, some of these central Pacific warmings had two, some one. There can even be a coastal warming with no central warming.

As it turns out, the official winter outlook has an El Niño look about it despite the forecasters' shunning of all El Niño predictions. The map patterns "are consistent with El Niño," says Gilman, "but we came to it for other reasons." Those reasons included conditions during earlier seasons and the presence of cold water south of the Aleutian Islands this fall. If this El Niño were to persist, says Gilman, changes in the outlook would involve enlargements to the areas of abnormal temperatures, for example, not new patterns. But even if El Niño were perfectly predictable, the outlook would not be much stronger than its stated 60 to 65% chances, which is a bit better than flipping a coin. The North American manifestations of El Niño are simply too variable to allow greater confidence. ■ **R.A.K.**