Computer Models Gaining on El Niño

Simulations of the ocean and of the atmosphere during an El Niño give hope for models coupling the two and hint at why mid-latitude effects are so variable

One observer called it "a real shoot-out", another less dramatically a grand "show and tell." Nine groups of researchers had inserted the warming of tropical ocean waters during the century's greatest El Niño, that of 1982–1983, into their computer models of the world's atmosphere. Then they let the mathematical equations of the models determine how the atmosphere would react. At a gathering* in Liège, Belgium, last month, the groups learned how their models had done. Very well, it turned out. That provided the best example to date of the new ability of general circulation models (GCM's) to simulate the response of the tropical atmosphere to ocean warming, an essential step to understanding and prediction.

Recent success in simulating the inverse process—the response of the ocean to a specified change in the atmosphere—opens the way toward combining atmospheric and oceanic GCM's into a single interactive model. Such a coupled model would be an essential tool in the study of El Niño because this phenomenon is obviously the child of both the ocean and the atmosphere.

In the past modelers had studied the effect on the atmosphere of a typical El Niño ocean warming, but the most recent warming (1982–1983) was far from typical (*Science*, 2 September 1983, p. 940). It arrived in the spring in the central Pacific rather than in the winter near the South American coast. It seemed the toughest test yet of the models.

The most crucial part of the test was the simulation of the location of the heavy rains associated with all El Niños but found particularly far to the east in 1982–1983. "Most of the models gave a very reasonable eastward shift, just as was observed," notes J. Shukla of the University of Maryland, chairman of the Liège session. "That was a very remarkable result." Some models did better than others in duplicating the magnitude of the enhanced rainfall, but the wind changes in the models were much like those that characterize the Southern Oscillation, the atmospheric change associated with an El Niño.

*Sixteenth International Liège Colloquium on Ocean Hydrodynamics/Symposium on Coupled Ocean-Atmosphere Models, held 7 to 11 May.

Perhaps the single most impressive atmospheric simulation presented at Liège was that of N.-C. Lau and Abraham Oort of the Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton, New Jersey. Instead of running their model through a few months or a year of changing sea-surface temperatures, the GFDL group simulated the atmospheric response to actual sea-surface temperature variations from 1962 to 1976, which included four El Niños. As in shorter runs with other models, the large-scale circulation of the model tropics closely resembled the observed patterns of those 15 years. The ocean temperature variations actually accounted for up to 70 percent of the variance in the simulated weather patterns in the tropics, a considerable proportion in the atmospheric modeling business.

> Computer models may be able to forecast general weather patterns beyond the 15-day theoretical limit.

As Shukla points out, the success of GCM's in simulating tropical circulation patterns suggests that computer models may be able to forecast the weather—or at least general weather patterns—beyond the 12- to 15-day limit implied by theoretical studies (*Science*, 6 May 1983, p. 590). This theoretical limit is enforced by the impossibility of knowing the present weather in sufficient detail. The inevitable errors in representing the model's starting point—the present weather—must multiply and cascade into simulations of the future until the model predictions bear no resemblance to the actual weather.

The hope has been that, because conditions at the boundaries of the atmosphere—such as the temperature of the sea surface or the amount of land covered by snow—change more slowly than the atmosphere itself, they would tend to steer the atmosphere in a direction that could be foreseen more than a couple of weeks into the future. For this mechanism to work, though, the atmosphere would have to take considerable notice of boundary conditions. The tropics, at least, do, or the present models could not perform so much better when actual rather than average sea-surface temperatures are used.

GCM simulations of El Niño and the Southern Oscillation (ENSO) have also shed more light on how the weather in the tropics during an ENSO episode can affect the weather over the United States more than 5000 kilometers to the north (*Science*, 7 May 1982, p. 608). Meteorologists had noted a series of alternating high- and low-pressure centers in the upper atmosphere that arced northward from the atmospheric disturbance induced by an El Niño's warming. This pressure pattern crossed North America in a way that could redirect the winds that steer the weather, as happened during the brutal winter of 1976–1977. Theorists in turn saw the pressure pattern as a possible expression of an atmospheric wave traveling northward to directly influence the weather.

Recent atmospheric GCM simulations by John Geisler of the University of Utah and Maurice Blackmon and his colleagues at the National Center for Atmospheric Research (NCAR) have shown that a wave traveling between the tropics and mid-latitudes may not alone provide the observed connection. As they moved the model's anomalously warm surface waters eastward from near the date line in the western Pacific, where they were during the moderate 1976–1977 El Niño, the Pacific–North American pattern of upper atmosphere highs and lows did not change. It should have changed if it is driven directly by a propagating wave.

Instead of generating a direct wave, says Blackmon, the tropical disturbance created by the warmer equatorial water may provoke an unstable response in the extratropical atmosphere as a whole, the so-called normal mode response. It can be likened to the striking of a drumhead, which tends to vibrate in the same pattern no matter where it is struck. As suggested last year by Adrian Simmons of the European Center for Medium Range Weather Forecasts, John Wallace of the University of Washington, and Grant Branstator of NCAR, the same pattern in the atmosphere might appear whether the disturbance was somewhere in the tropics or the mid-latitudes.

The pattern and position of the Pacific–North American connection may be unchanging, but whether it is strong, weak, or shows up at all has been far less predictable—the winter of 1976–1977 (accompanied by a moderate El Niño) was brutally cold in the East, that of 1982–83 (a record-breaking El Niño) was mild. Geisler and Blackmon found that the difference may lie in part in the position along the equator of the unusually warm water. When they moved it eastward from the 1976–1977 date line location, the strength and reliability of the mid-latitude response decreased at each of two more eastward positions. Timothy Palmer of the British Meteorological Office has also found a particular sensitivity in the GCM to surface warming in the western Pacific, where the already warm water gives a boost to the resulting atmospheric disturbance. The tropical far-western Pacific, he notes, was 1°C warmer than normal in 1976–1977.

Another highlight at Liège was the oceanic equivalent of the atmospheric GCM's presented by George Philander of GFDL. Like its atmospheric counterpart, this model contains mathematical descriptions of how fluids flow, but the fluids are the tropical waters of the ocean. Instead of the ocean temperature determining atmospheric circulation, it is the surface winds that are specified and that drive ocean currents. And once again the model's circulation, that of the ocean, is determined by its boundary conditions. "We can reproduce all oceanic features quite accurately," says Philander. The simulated and observed oceans "are remarkably similar."

Thus, meteorologists and oceanographers possess complex, reliable models of their respective parts of Earth. Modelers are focusing on the tropics because both air and water in that zone are so responsive to each other and the behavior of both components is uncomplicated by the small, variable eddies typical of mid-latitudes. The next step essential to understanding and predicting that behavior, including ENSO episodes, is to eliminate the predetermined, unresponsive boundary conditions of each model and form a single ocean-atmosphere GCM. In contrast to their uncoupled versions, coupled tropical models will be unstable, but it is the resulting variability, the ENSO episodes, that must be understood. Researchers believe that in the tropics they have the best chance to do so.—**RICHARD A. KERR**

Interferometry in Space

At the American Astronomical Society's meeting in Baltimore last month,* the emphasis was on astronomy in space. Not only was the meeting itself cohosted by the Space Telescope Science Institute of Johns Hopkins University but there were sessions on the instruments of the Space Telescope, on mechanisms for allocating observing time on Space Telescope, and on the National Aeronautics and Space Administration's plans for future astronomical missions beyond Space Telescope.

However, in many ways the most intriguing session was a 1-day workshop on optical interferometry in space. Interferometry is a way of combining the signals from several telescopes so as to produce images as fine-grained as those from a single giant telescope. It has been a staple of radio astronomy for years, of course, but at centimeter wavelengths it is relatively easy: the receivers only have to maintain their positions to within a fraction of a centimeter. At optical wavelengths, however, interferometry is an extraordinary challenge: tolerances are on the order of Ångstroms.

Recently, however, given the availability of extremely accurate laser ranging devices and the rapid advances in active optics (*Science*, 16 April 1982, p. 280), people have begun to take the idea quite seriously. Several optical interferometers are already operating on the ground, and just within the last year or so there has been a spontaneous groundswell of interest in interferometry in space. A day-long workshop at the Baltimore meeting featured more than half a dozen conceptual designs from as many independent groups. In fact, the workshop was organized by Irwin I. Shapiro, director of the Harvard-Smithsonian Center for Astrophysics (CFA), as a first step in pulling these ideas into a coherent program of interferometer missions for the 1990's.

There is no doubt about the scientific value of such missions. A space-based imaging interferometer could achieve spatial resolutions at the milli–arc second level, one or two orders of magnitude better than those of space telescope. That would be sufficient to resolve the details of surface activity on some of the nearby stars, and perhaps even to examine the central regions of quasars. Astronometric interferometers, either based on the shuttle or free-flying, could measure stellar positions to within a few *micro*–arc seconds. Among other things, such a system could easily detect the perturbations in a star's motion due to Jupiter-sized planets. Not only would it allow for the detection of other solar systems, in fact, but it would allow for a comprehensive statistical survey of solar systems in the neighborhood of the sun.

*164th Meeting of the American Astronomical Society, 10 to 13 June 1984, Baltimore, Maryland.

IRAS

Launched in 1983, the Infrared Astronomy Satellite, IRAS, performed the first all-sky survey at infrared wavelengths—specifically, at 12, 25, 60, and 100 micrometers (*Science*, 1 July 1983, p. 43). In the 7 months since the completion of the mission, the IRAS scientists have continued to refine their data and their understanding. Several sessions in Baltimore were given over to the results.

Infrared Bright Galaxies: In most galaxies, including our own, the infrared and visible luminosities are roughly the same. However, IRAS discovered a new class of galaxies, comprising about 5 percent of all galaxies, that are a bit like a hot frying pan: dim in the visible and bright in the infrared, by a factor of 50 to 100. In fact, their total luminosity puts them in the quasar class. The most dramatic example, Arp 220, has power output equivalent to 2 trillion suns.

It is hard to say what these things are, exactly. Many are very distant and unresolved objects. On the other hand, many of those that *are* close enough to show structure often seem abnormal and disturbed. In fact about 30 percent of the infrared bright objects appear to be pairs of galaxies in the process of collision or merger. So one reasonable model is that shock waves produced in the collision are triggering bursts of star formation; certainly it is true that star formation produces lots of infrared emission in normal galaxies. Unfortunately, certain other spectral features are not