Science doesn't usually occupy center stage at a global summit. But next month's Earth Summit in Rio de Janeiro, officially known as the United Nations Conference on Environment and Development (UNCED), will be different. As delegates sit down to confront the future of the planet—how humanity can best develop it while protecting the environment—they will be debating policy in the shadow of research findings and technological developments like the ones detailed in this special news section.

Science, after all, has defined some of the key problems facing the UNCED delegates: the greenhouse warming, the loss of biodiversity, and the global changes that are affecting agriculture. And it is suggesting the beginnings of solutions. "Chemical prospecting" for new medicines in the tropical rain forest may be one way to make biodiversity pay, and environmental technologies promise to reduce emissions of greenhouse gases or even turn them into useful products. Further insight into problems and solutions is likely to come from the flood of multidisciplinary research—such as the studies of Antarctic plankton shown in the background photograph—under way in newly established global change centers.

But science can only frame the debate. Now it's up to the policy makers to weigh the risks of global change, and the costs and benefits of slowing it.

–Tim Appenzeller, Editor

Special Research News Section

Also see the editorial by AAAS president Sherwood Rowland, who first sounded the alarm over damage to the ozone layer, on p. 1109.

ROBIN ROSS AND LANGDON QUETIN/UCSB

Greenhouse Science Survives Skeptics

Much of the United States was hot and dry in the summer of 1988. So when National Aeronautics and Space Administration (NASA) climate expert James Hansen put a spark to the dry tinder of public opinion with his claim that global warming was here, a fire storm of public concern was inevitable. But in parts of the scientific community there was just as inevitable a response—skepticism. Experts such as noted meteorologist Richard Lindzen of the Massachusetts Institute of Technology (MIT) not only saw no evidence of greenhouse warming, they also saw no clear prospect of a significant warming in the future. The brawl had begun and, with a conservative administration in power—one loath to impose regulations on industry—environmentalists' hope of any sort of national commitment to limit greenhouse emissions seemed a pipe dream.

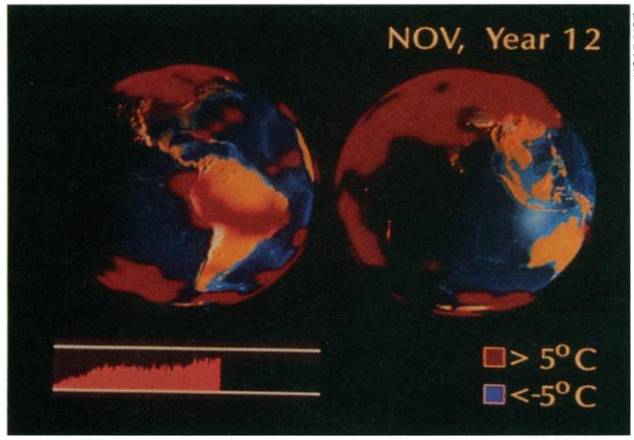
And yet over the past 4 years, the tempest has abated, scientific support for a middle ground has solidified, and, remarkably, even the Bush Administration is dropping its unqualified opposition to action on the greenhouse threat...just in time for next month's United Nations Conference on Environment and Development, to be held in Rio de Janeiro. What accounts for the palace revolution? John Sununu's departure may have removed the single biggest skeptic in the White House, and repeated studies have made clear that at least modest steps against greenhouse warming needn't cost an arm and a leg.

But the Administration is also hearing from the scientific community that the consensus is stronger than ever—greenhouse warming does pose a serious threat for the planet's future. Indeed, a four-agency memo leaked to the press at the end of last month, entitled "U.S. Views on Global Climate Change," hews closely to the latest assessment of greenhouse science released this month by the Intergovernmental Panel on Climate Change (IPCC). Echoing the IPCC, the memo concedes that continued increases in greenhouse gases will likely lead to "significant changes in the climate system."

To many scientists, there's an irony in the Bush Administration's recent "discovery" of the greenhouse effect. The Administration memo cited "a consensus view of a broad range of scientists, including most U.S. scientists," and quoted likely limits to greenhouse warming due to a doubling of carbon dioxide as a modest 1.5°C at the lower end and a hefty, if not catastrophic, 4.5° at the upper end. That's the same range that National Academy of Sciences panels have been coming up with for the past 15 years—and that the Bush Administration had largely ignored, citing in its defense the scientific uncertainties.

But wait a minute: If eminent panels have been pushing the same mainstream position for more than a decade, why has the public been treated to dueling scientists for 4 years? Climatologist Robert Balling of Arizona State University, himself something of a greenhouse skeptic who has attracted public attention for his views, blames the media's tendency to accord high visibility to scientists on either extreme of the question. "The public gets the idea that [a few vocal scientists] represent the scientific community. They don't, but they make for the best fight on 'Good Morning America.'"

Plenty of scientists observed the



NCAR/NSF

A warming world. After 12 years of doubled carbon dioxide, a model earth has warmed more than 5°C over large areas.

tussle with interest, but eventually a quiet majority found fault with both extremes. When Hansen, director of NASA's Goddard Institute for Space Studies in New York City, insisted that the half-degree warming of the past century was driven by the steady increase of greenhouse gases, most greenhouse researchers eventually concluded that although the warming is consistent with an intensifying greenhouse, it is not clearly a result of it.

At the same time, however, mainstream scientists saw the objections of greenhouse skeptics as falling short. Some skeptics argued that the greenhouse might not warm the planet much because the sun, now possibly at a long-term peak in activity, might dim slightly in the next century, or because plants would simply suck up most of the added carbon dioxide. But most researchers viewed either salvation as speculative. Other skeptics saw an inconsistency between the greenhouse predictions and various temperature records. The United States, for example, showed no long-term warming, but such a small portion of the globe—just 5%—could easily have avoided warming so far.

A drafty greenhouse. Lindzen's skepticism drew particular attention, though, because of his prominence and the detailed case he presented. In 1989, he proposed that the computer climate models predicting a few degrees' warming for a doubling of carbon dioxide misrepresented a key process that could limit warming to a few tenths of a degree—that is, nothing to worry about (*Science*, 1 December 1989, p. 1118). Lindzen argued that the greenhouse effect has an inherent limit—indeed, one that has nearly been reached, due to the water vapor and other natural greenhouse gases that already warm the atmosphere by 33°C. His argument went as follows: Any additional warming from newly added greenhouse gases would boost convection in the tropics, pumping more warm air up through towering clouds, which wring out most of the air's moisture. That would flood the upper troposphere, above the level of the cloud tops, with dry air. And the dry air would reduce the overall greenhouse effect, limiting the net warming to minor proportions.

Such a renegade proposal coming from a prominent researcher made front-page news and prompted considerable new study. But after several years of scrutiny, most climate researchers would agree with IPCC coauthor John Mitchell of the United Kingdom's Meteorological Office in Bracknell, who says: "It's been interesting, but a lot of circumstantial evidence supports the conventional wisdom." The most telling evidence against Lindzen's self-limiting greenhouse includes satellite and balloon observations showing that water vapor in the upper troposphere increases, not decreases, whenever and wherever the lower troposphere is warmer—in summer versus winter, in the warm western Pacific versus the cooler eastern Pacific.

Lindzen rejects such observations as imprecise and perhaps irrelevant. But some researchers admit they also have trouble with his style of argument, detecting something of a double standard in his notion of uncertainty. "Dick does a good job in pointing out what the uncertainties are" in mainstream greenhouse predictions, says modeler James Risbey, a colleague of Lindzen's at MIT. "I have less faith in what he says when he talks about smaller climate changes and lends a certainty to his own predictions. The very uncertainties he relates to standard predictions also apply to his own."

Risbey and others in the mainstream readily admit that greenhouse science is still pervaded by uncertainties—about the magnitude of the threat, for example (see box). Given such uncertainties, some researchers are arguing for a delay in reining in greenhouse emissions while the science settles down. Climate modelers Michael Schlesinger and Xingjian Jiang of the University of Illinois at Urbana-Champaign sparked the debate with calculations in *Nature* (21 March 1991, p. 219) that suggested that even if the eventual warming turns out to be at the high end of the scale, little harm would come of waiting 10 years. That would leave time for an intensive effort to refine climate models on massively parallel computers, 1000 times faster than today's supercomputers, they argued. "No one is proposing we wait 30 years," says Schlesinger, "but I don't see any compelling argument that we have to begin immediately."

But many scientists can't agree with even this modest wait-and-see approach. The first

Greenhouse Uncertainties: Adjusting the Heat

With the scientific and political battle over the reality of the greenhouse threat largely behind them (see main text), climate researchers are getting down to the next order of business: refining their predictions of just how much warming the world is in for. To do so, they need to resolve uncertainties about how the atmosphere, ocean, and biosphere will respond to a warmer world—and how those responses will feed back to affect climate change.

Clouds. The single largest uncertainty in the climate models is the behavior of clouds as the world warms. Will clouds that can trap heat, such as wispy cirrus, increase in abundance, or will the low-lying decks of clouds that form over the ocean predominate, reflecting additional sunlight back into space and cooling the atmosphere? In one model, created by researchers at the United Kingdom's Meteorological Office, the warming due to a doubling of carbon dioxide dropped from 5.2°C to 1.9°C when the model was switched from one way of rendering clouds to another "equally plausible" way. Getting clouds right will take 10 to 20 years because researchers must understand better what determines the mix of clouds in the real world and then get computer clouds to act like the real ones.

NCAR/NSF

Dangerous beauty? Clouds' response to global warming could moderate or magnify the climate change.

Oceans. The watery portions of the planet play diverse roles in greenhouse warming. Their slowness to warm will delay the full extent of atmospheric warming by decades, though no one is sure how many. They absorb more than one-third of carbon dioxide emissions, but no one knows whether they will continue doing so. And their circulation modifies climate, although climate change could alter their circulation, perhaps abruptly.

Miscellaneous feedbacks. The interconnected system of ocean-atmosphere-biosphere could change its behavior in a host of other ways in response to warming, creating other feedbacks. Ice and snow, for example, might recede, exposing darker ground or ocean that would absorb more sunlight and accelerate the warming. Or the production of methane—a greenhouse gas—from wetlands might increase. Most of the feedbacks researchers have been able to imagine tend to enhance any warming. And most are not included in present climate models.

With uncertainties like these, no wonder schools are sprouting global change programs (see p. 1146) like dandelions on a spring day.

–R.A.K.

to respond were Risbey, Mark Handel, and Peter Stone of MIT, writing in the 31 December 1991 issue of *EOS*, the weekly newspaper of the American Geophysical Union. The MIT group argued that Schlesinger and Jiang's supercomputer effort wouldn't narrow the uncertainties enough. And a decade, they say, will see only the beginning of crucial observations of the behavior of oceans and clouds—two key sources of uncertainty. Risbey and company's doubts echo those in a 1990 IPCC report, which foresaw the cloud and ocean uncertainties narrowing only in the 10- to 20-year range, by which point the globe might be committed to major climate change.

Nasty surprises. The other reason for not waiting is uncertainty itself, say Risbey and others. The possibility that greenhouse-induced change could turn out to be much more dramatic than any model predicts is spooking a generation of earth scientists who remember the nasty surprise sprung by stratospheric ozone. By the late 1970s, scientists knew of the potential for damage by manmade chlorine compounds, but their scenarios suffered from uncertainties and lacked a smoking gun. As a result, public interest in the problem declined. Then, out of the blue, atmospheric chlorine burned a hole in the ozone layer over the Antarctic and began eating away at the ozone over mid-latitudes. Scientists had simply overlooked ways that natural atmospheric particles could boost chlorine's destructiveness by a factor of 10.

Greenhouse specialists, too, are wondering what they might have overlooked. Perhaps an abrupt change in ocean circulation, Wallace Broecker of Columbia University's Lamont-Doherty Geological Observatory has suggested—although some studies have now discounted that idea. Or perhaps unanticipated feedback from polar ice caps or green plants, other workers venture. "It's a matter for concern," concedes Schlesinger. "How you deal with that depends on your philosophy."

The philosophy that many scientists contacted by *Science* are now espousing amounts to buying some insurance—in the form of no-cost or low-cost reductions in greenhouse gas emissions—against the possibility that the higher predictions of global warming turn out to be right or some nasty surprise is lurking in the greenhouse. And that notion of prudence seems to be catching on at last in the White House.

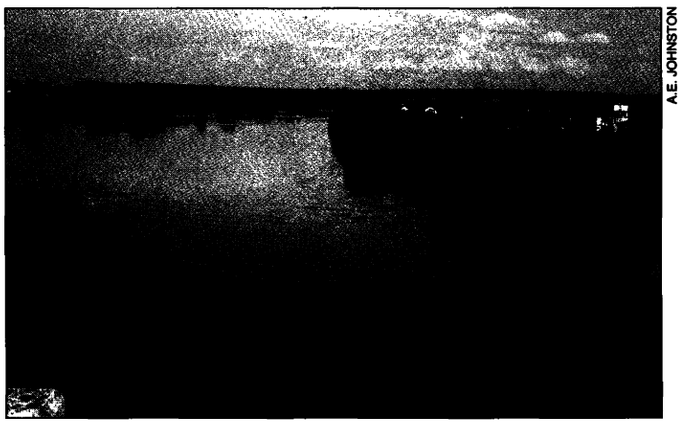
–Richard A. Kerr

ADDITIONAL READING

- J.T. Houghton *et al.*, Eds., *Climate Change 1992: The Supplementary Report to the IPCC Scientific Assessment* (Cambridge University Press, 1992).
- W. Kellogg, "Response to Skeptics of Global Warming," *Bull. Am. Met. Soc.* **74**, 499 (1991).
- R.S. Lindzen, "Some Coolness Concerning Global Warming," *Bull. Am. Met. Soc.* **71**, 288 (1990).

AGRICULTURE

Does Global Change Threaten The World Food Supply?



A.E. JOHNSTON

Land on the run. A river in Paraná state, Brazil, runs red with soil eroded from deforested land.

When most people think of global change, they think of its impact on the natural world: the loss of animal and plant species, the warming of the climate, the destruction of ozone. But global change is also taking its toll on one of humankind's most important activities—agriculture. Indeed, a distressing turn of events has already taken place in Asia's rice paddies and Mexico's potato fields, unnoticed by most of the developed world. After 3 decades of continuous increase, crop yields have leveled out or, worse, dropped, over the past few years.

And that's contributing to an alarming trend. In almost 70% of developing countries, population growth is outstripping gains in food production, reports the Washington, D.C.-based secretariat of the Consultative Group on International Agricultural Research (CGIAR), an informal association that supports 16 international agricultural research centers. "For the first time in modern history," says Paul Ehrlich of Stanford University, "absolute global food deficits may soon compound inequities in food production and distribution in causing famine."

Ehrlich, a population biologist, is known for pessimistic scenarios. But many agricultural researchers agree with him on this one. Uma Lele, an agricultural economist who until recently was with the World Bank and is now at the University of Florida, says, "A general impression remains that the Green Revolution has permanently solved the food problem. But the harvests of recent years suggest otherwise." Underlying this sputtering productivity, she and other researchers say, are broad global trends that include the loss and degradation of arable land and the increased genetic uniformity of world food crops, which opens the way for pests and diseases to have a devastating impact.

So far the list of causes doesn't include global climate change. Some researchers fear that in the future, though, the added stress of a climate that may become warmer or drier in key production areas could take a further toll on global agriculture, with catastrophic results. Others are more sanguine, pointing to agriculture's history of adapting to a range of climates. But whether they see the flattening yields of the present as a warning for the future or an anomaly, researchers are joining in a call—likely to be echoed at next month's United Nations Conference on Environment and Development in Rio de Janeiro—for the development of "sustainable" agricultural strategies that would stem the loss of land and increase crop diversity.

To some extent, researchers say, agriculture is a victim of its own success. For the past 30 or 40 years, gains in global food production have exceeded population growth throughout the world, parts of Africa excepted. In Latin America and much of Asia, for example, yields more than doubled over that period. But those boom harvests were sparked by the agricultural programs of the Green Revolution, which had built-in limits. Already, says Michael Collinson of CGIAR, "the second generation problems [of the Green Revolution] are coming home to roost."

Is the revolution over? The limits of the Green Revolution stem from its reliance on a few high-yield crop strains and intensive use of pesticides, fertilizers, and irrigation. Not only are insects becoming resistant to the pesticides, but high costs and concern about health risks are starting to restrict pesticide and fertilizer use. And crop strains that were widely planted because they promised high yields—and for a time delivered them—are now falling victim to new diseases: Witness the potato fields of Mexico where, according to Luis Herrera-Estrella of the Centro de Investigacion y Estudios Avanzados (CINVESTAV) in Irapuato, Mexico, "yields have decreased in recent years despite increased acreage planted to the crop. Typically,