group that includes the tuberculosis bacillus. Plenty of experiments had suggested that interferon-γ is critical for activating macrophages, the scavengers that scarf up parasites and parasite-infected cells. It's importance was also apparent in living animals, since mice treated with interferon-γ antibodies succumb to such infections. So it was a good bet that the knockouts would meet a similar fate—and they did.

What's more, experiments by both groups on cells from the knockout mice confirm that interferon-γ is needed for production by the macrophages of nitric oxide, which serves as their antiparasite poison. There are no surprises in this, says Schreiber. But he adds, "You'd like to be able to prove the same point in at least two if not three different ways," and the mice provide a "more definitive" confirmation of previous results.

But bigger things than such confirmations clearly lie ahead for these mice. It should be possible, Coffman says, to answer such major questions as which of the cells that produce and respond to interferon-γ are most crucial to different immune responses. One way to do this is to systematically add back an active interferon-γ gene or interferon-γ receptor gene to each of the different cell types that make or respond to the cytokine. Aguet says his group is already beginning such an approach with their receptor-knockout mice, adding back the functional interferon-γ receptor in such a way that it will be expressed in only one cell-type, such as macrophages. "This is a way to formally show that the macrophage is actually the crucial cell that needs to respond to interferon-γ," he says.

Besides helping to unravel such basic questions in immunology, the mice also seem likely to provide useful models for understanding diseases caused by intracellular parasites, such as tuberculosis. Mice have been less than ideal for studying tuberculosis, says TB researcher Ian Orme, of Colorado State University, because they don't develop the full-blown disease. But both Orme's group, and that of Barry Bloom at Einstein University, working in collaboration with the Genentech group, have found that the interferon-γ knockout mice develop severe tuberculosis. "I'm very optimistic, and very excited about this," Orme says. "It may prove a very promising model for experimental chemotherapy."

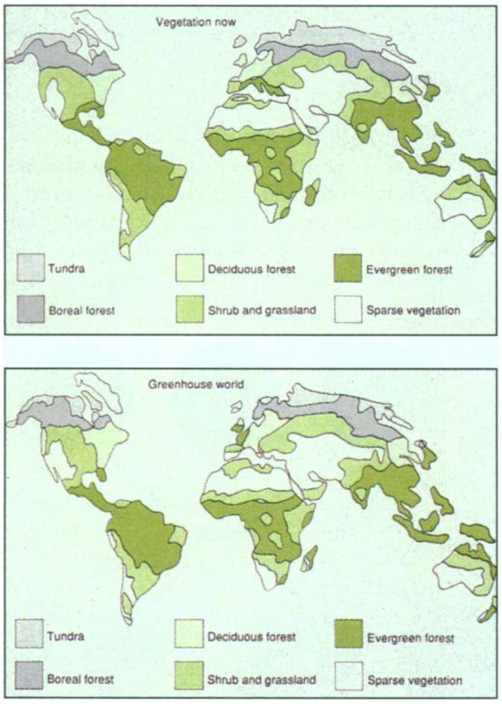
So even in a world becoming increasingly crowded with knockout mice, these two mouse strains promise to be in high demand. "For almost everything I study, interferon-γ is the key cytokine," says immunologist Alan Sher, who studies the immune response to parasitic infections at the National Institute of Allergy and Infectious Diseases. "These mice are the most interesting knockouts I can get my hands on."

–Marcia Barinaga

GLOBAL CHANGE

Ecologists Put Some Life Into Models of a Changing World

While 300 scientists gathered in a former casino in Ensenada, Mexico, in late January to talk about global change, bulldozers outside were clearing debris from roads and river channels after 2 weeks of disastrous flooding. The floods, the result of the heaviest rain in decades, provided a vivid reminder of why the International Geosphere-Biosphere Program (IGBP) had brought these researchers from 50 countries together: to talk about ways of reducing the uncertainties in predictions of global change. Nobody inside the hall was calling the rains a harbinger of climate change, but many scientists believe that, as human activity alters the atmosphere and



IAN WOODWARD

A green migration. Existing vegetation *(top)* shifts in a warmer world *(bottom)*, as simulated by DOLY.

the climate, weather extremes like the one so evident outside the hall will strike parts of the globe more frequently. Just where those changes might occur—and what their impact might be—is, however, beyond the ability of today's climate models to predict.

That's one reason scientists at the conference* were talking so excitedly about a historic extension of the models that will take place starting this spring. For the first time, computer models of a green Earth banded with forests, grasslands, and swamps will meet simulations of the atmosphere and climate. At the end of each encounter, which will take place in computers at the UK Meteorological Office near London, the Laboratory for Modeling of Climate and Environment in Paris, and the Max Planck Institute for Meteorology in Hamburg, a new landscape and climate will emerge. Among them: a future Earth altered by a doubling of the atmosphere's carbon dioxide.

That world has been described often enough by one party to this spring's marriage: general circulation models (GCMs), computer models of atmosphere and climate that project a global warming of 1.5 to 4.5° C by the middle of the next century, when human activity may have doubled the amount of CO_2 in the atmosphere. But GCMs have been criticized for treating the earth as a dead planet, inert and unresponsive to climate. That's a major omission, because a shifting climate will have some of its sharpest impacts on ecosystems. What's more, ecosystem changes—the replacement of tundra by forest, grasslands by desert—may also feed back on climate change, influencing its overall severity and how it affects the world region by region. This spring's encounters will mark a first step toward filling that gap.

By coupling GCMs with computer models of the world's vegetation zones so that each climate change is allowed to affect the distribution of plants and each biological change is given a chance to affect climate, two international research teams led by botanist Ian Woodward of the University of Sheffield and plant ecologist Colin Prentice of the University of Lund hope to come up with a more complete picture of global change. Woodward, Prentice, and their climate modeling colleagues in London, Paris, and Hamburg aren't promising a lot of detail. Eventually, they hope to refine their predictions by cross-fertilizing their models with other vegetation models describing details of plant behavior and processes such as photosynthesis and decomposition.

But many of the IGBP scientists who gathered in Ensenada were dazzled by how far and how fast things have moved. "The maturity of this interface between the physical climate focus and biology has happened so much

*"Reducing Uncertainties in Global Change," Third Scientific Advisory Council meeting of the International Geosphere-Biosphere Program in Ensenada, Mexico, 25-29 January.

faster than expected," says biological oceanographer James McCarthy of Harvard, chair of the IGBP Scientific Committee. Adds ecologist Brian Walker of Australia's Commonwealth Scientific and Industrial Research Organization: "Four or 5 years ago people were saying maybe in a couple of decades. I'm astounded that in 1993 it [coupling the models] will happen."

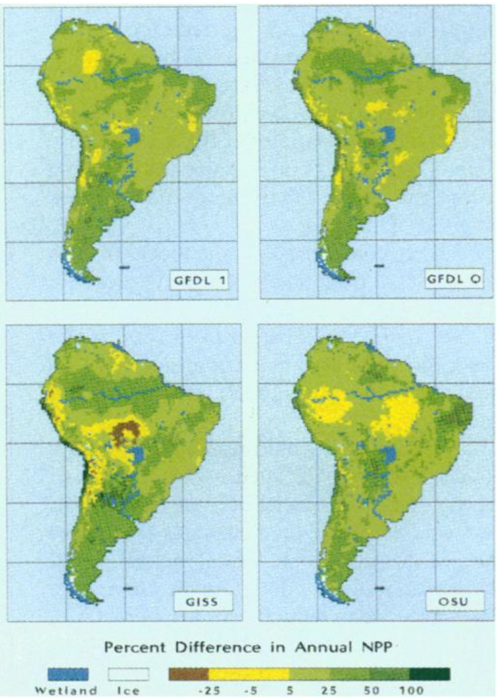
A grid of green. The ecosystem modelers have come this far only thanks to some dramatic simplifications. While ecologists are used to considering small networks of species in localized areas, the modelers have to average complex phenomena, such as how individual plants respond to temperature, CO_2, and precipitation, over swathes of terrain tens of kilometers on a side. The job would be easier, notes McCarthy, if biodiversity could be realistically portrayed as "a uniform green slime, turning off and on with light, temperature, and water"—but in nature, regions as large as the grid squares contain hundreds or thousands of plant species.

Prentice's model, called BIOME, simplifies this diversity into 14 general types of vegetation, such as desert, savanna, and tropical rain forest, which get assigned to 60-kilometer squares in a grid representing the earth's surface. In the model, the pattern of vegetation depends on three critical variables: minimum temperature, "degree days" (essentially a measure of the growing season), and moisture. As these variables change, the model reshuffles vegetation zones across the earth's surface. Woodward's model, which he calls DOLY (creatively derived from Dynamic Global Phytogeography Model), works in much the same way.

Even that simple picture of global vegetation doesn't mate neatly with climate models, however. Geographic scale is one mismatch. Ecologists find it difficult to create meaningful descriptions of vegetation on a scale any coarser than a grid 50 to 60 kilometers on a side, while climatologists, daunted by the amount of computation required to model the circulation of the atmosphere, haven't been able to refine the grid squares in their GCMs below about 300 kilometers on a side. Another mismatch is timing: Ecological modelers prefer monthly time steps at the shortest, and for geographical shifts of whole biomes, years or decades. For modeling climate changes, in contrast, winds and temperature have to be recomputed every 20 minutes for each grid cell.

By averaging over multiple time intervals or grid squares, though, Prentice has been able to test his model by coupling it to reconstructions of past climates. In one case, he and his colleagues fed in the ice age climate of 18,000 years ago, as reproduced by a GCM at the Max Planck Institute in Hamburg. The BIOME researchers then compared the resulting simulation of ice age vegetation zones with the actual prehistoric landscape, based on fossil evidence. "The model did a remarkably good job," says Prentice.

In such exercises, the interplay between models has been one way: The climate predictions drove the ecosystem model, but the resulting vegetation changes weren't used to refine the climate prediction. In this spring's effort to look into the future of climate and the global ecosystem, the models will interact fully for the first time. In each time step, a GCM—the Hamburg model for BIOME and a GCM at the UK Meteorological Office for DOLY—will set the climate variables for each square in a global grid, and the ecological model will remap the vegetation types onto a new landscape. This new vegetation pattern will in turn alter the earth's "surface boundary conditions," such as its reflectiveness and the roughness of its vegetated surface, which can affect winds. The changed surface conditions will then drive the climate to a new equilibrium.



JERRY MELILLO

Four looks at the future. The Terrestrial Ecosystem Model simulates changes in plant productivity in South America under various climate forecasts.

Ecologists are quick to point out that even after this first interactive modeling of climate and the biosphere, much of the picture will still be missing. For one thing, models such as BIOME and DOLY don't model all the processes through which ecosystem change might affect climate and vice versa. They leave out the possibility that as the atmosphere changes, plant-driven processes such as carbon dioxide uptake and water cycling might also change, putting their own stamp on climate. A rise in carbon dioxide or temperature, for example, could spur plant growth, storing away some of the excess carbon dioxide in organic matter (see box). Or a changed ecosystem might cycle water more efficiently through roots and leaves, affecting local precipitation and cloud cover.

To fill in this blind spot in global ecosystem modeling, IGBP researchers are looking to another category of biological models, known as dynamic process models. An example is the Terrestrial Ecosystem Model (TEM), developed by a team led by ecologist Jerry Melillo of the Marine Biological Laboratory at Woods Hole and mathematician Berrien Moore III of the University of New Hampshire. TEM models how climate change affects the cycling of carbon and nitrogen (a key nutrient that limits the potential for added plant growth in many parts of the world) in 50-kilometer grid cells distributed across the vegetated surface of the planet. The mathematical descriptions of processes such as photosynthesis and decomposition depend on the vegetation of each grid cell, which can be one of 18 ecosystem types.

This process model, however, doesn't allow any ecosystem, from tundra to rain forest, to shift into new grids as conditions become unsuitable. Since that's the province of BIOME and DOLY, would-be forecasters of a changed world look forward to combining elements of both models into "a truly dynamic global vegetation model," says Walker.

Details, details. Even that model would suffer from some drastic oversimplifications. While TEM doesn't allow vegetation belts to shift, BIOME and DOLY both assume that plants can shift at will across the landscape, ignoring what is known about the maximum rates of change that each vegetation type can endure. These models also use only a single dominant plant type to describe each ecosystem, "yet we know most ecosystems have mixed stands or mixtures of trees and grasses," says Walker. And competition between plant species, he notes, can affect the replacement of one vegetation type by another.

To add such realism, other ecologists are developing "bottom-up" models that try to describe how the mixture of species and other complex factors that vary on small scales—soil texture or slope angle, for example—influence an ecosystem's response to a change in, say, precipitation or temperature. So many of these bottom-up models are in the works that IGBP has put together an international network based in ecologist Herman Shugart's lab at the University of Virginia. The organizers hope that the modelers will pool their strategies for representing ecological complexities. "The idea is to share modules before they become models," says Walker.

Incorporating these ideas into the global models requires simplifying them, and those

Could Plants Help Tame the Greenhouse?

It's easy to see how climate change might affect the globe's vegetation, driving hardwood forests into regions now covered with evergreens and causing deserts to shift (see main text). It's less easy to picture the other side of the coin: biology's impact on the atmosphere. So mathematician Berrien Moore III of the University of New Hampshire, who heads the International Geosphere-Biosphere Program task force on global analysis, interpretation, and modeling, staged a simple demonstration. He modeled the effects of a biosphere "fertilized" by increased CO_2—and found that it could first help, then hinder, human efforts to slow the buildup of greenhouse gases.

There are signs that increased plant growth may already be affecting the course of global change. Only about half of the 7 billion or so tons of CO_2 emitted each year by human activity remains in the atmosphere. About 2 billion tons seem to be soaked up by the oceans, leaving at least a billion tons unaccounted for (*Science*, 3 April 1992, p. 35). Support for the idea that the missing carbon dioxide is fertilizing greater plant growth—which then stores up the carbon—comes from studies of the seasonal rise and fall of CO_2, as growing plants "inhale" carbon in spring and summer and decaying leaves "exhale" it in autumn and winter. Since the mid-1960s the amplitude of those cycles has been increasing, suggesting a larger total biosphere.

To simulate such a biotic carbon "sink," Moore combined a simple model of CO_2 uptake by the ocean with an equally simple model of its uptake by photosynthesis on land and its release by deforestation and plant decay. He then "forced" this simple ocean-atmosphere-vegetation model with fossil fuel CO_2 emissions from 1860 to the present. As expected, his model ended up with too much carbon in the atmosphere. So he turned up photosynthesis, fertilizing plant growth in his model, until the rate of CO_2 buildup just matched the observed increase.

Moore then explored how this terrestrial carbon sink would respond if the CO_2 buildup slowed. The result: "If you were to cap the rate of CO_2 emissions from fossil fuel burning, [this terrestrial] sink would reduce the atmospheric lifetime of CO_2 by a factor of four or five." This cleansing effect would operate on timescales of years or decades, compared with centuries for the ocean, says Moore—fast enough to aid human efforts to slow the CO_2 buildup. "However, it doesn't do it forever." If at some point emissions cuts and the terrestrial sink succeeded in reducing atmospheric CO_2, plant growth would drop and CO_2 levels would bounce back up as all the extra biomass rotted away. That makes CO_2 fertilization a mixed blessing for those who would slow climate change, Moore observes.

–Y.B.

simplifying assumptions must be calibrated with real data. And that accounts for another major topic at the meeting: a series of large-scale field experiments by IGBP scientists on the interplay between vegetation and climatic factors such as carbon dioxide, temperature, and moisture.

One example discussed in Ensenada: the ongoing Long-Term Free-Air CO_2 Enrichment (FACE) experiments, in which a system of pipes and pumps is used to bathe a small patch of a natural ecosystem with an atmosphere containing double today's CO_2 concentrations. Existing efforts to describe the response of vegetation to a rise in CO_2 have to rely mostly on the results of short-term experiments done with individual plant species in greenhouses. But how much of a boost in plant growth would be seen in a real ecosystem depends on the mixture of species, which of the two photosynthetic pathways most of the plants use, and the availability of light, water, and nutrients, notes ecologist Harold A. Mooney of Stanford. Such complexities can be studied only in a real ecosystem.

The global change specialists gathered in Ensenada were well aware, however, that the biosphere isn't all green. There's another factor in global change: people, who are transforming the landscape as dramatically as climate ever will. So the biological and physical scientists welcomed emissaries from a third group: social scientists taking part in a new international program on Human Dimensions of Global Environmental Change. In collaboration with IGBP, the human dimensions group is planning a new project on land use and land cover change. The goal: To find a way to quantify human "forcing functions" —the human dynamics driving deforestation in Haiti, desertification in Mongolia, or the retreat of the Aral Sea—so that the models can reckon with human effects on the land and how they might influence global climate.

As one speaker noted, no model can track the future of rain forests by putting in CO_2 and temperature but leaving out chainsaws.

–**Yvonne Baskin**

Yvonne Baskin is a free-lance writer in San Diego.

PLANETARY SCIENCE

More Venus Science, or The Off Switch For Magellan?

Later this year an engineer at the Jet Propulsion Laboratory (JPL) may do something that's never been done before: shut down a still productive planetary probe because the National Aeronautics and Space Administration (NASA) couldn't come up with the pittance in additional funding required to extend the mission. The Magellan spacecraft has been a spectacular success since it began radar mapping of the surface of Venus in September 1990. But it completed its prime mission just 200 days later. NASA extended the $800 million Magellan mission until last fall, when the Bush Administration cut off funding and it began living off money that managers had scrimped from the previous fiscal year.

Mission scientists and some agency officials now want a mere $8.2 million for a bare-bones, seat-of-the-pants effort in which Magellan would probe the deep interior of Venus.The study of the internal workings of Venus is crucial, scientists say, to understanding what created the sometimes exotic geology of Earth's nearest relative. But the budget-strapped agency has yet to produce the funding, and if it doesn't the spacecraft will have to be shut down when the current money runs out in 3 months' time.

Planetary scientists are now worried that the threatened termination of the Magellan mission may be a harbinger of similar problems for the other three NASA spacecraft recently launched across the solar system that have yet to complete their prime missions. These include Galileo, whose goal is to explore the Jovian system, the Ulysses mission to study the sun's polar regions, and Mars Observer.

The problem is rooted in NASA's long-standing tradition of not planning for the likely costs of operating a spacecraft after it has completed its prime mission, defined as what the spacecraft's designers can more or less promise will be achieved. In Magellan's case, that was mapping 70% of the Venusian surface. But the science from a prime mission can fall far short of what spacecraft can achieve. They're usually capable of years of additional operations. Indeed, says Thomas Donahue of the University of Michigan, a veteran of the 14-year Pioneer Venus Orbiter mission: "Technologically, these [spacecraft] are built to last." In the absence of any