CLIMATE CHANGE

Studies Say—Tentatively—That Greenhouse Warming Is Here

Searing hot summers and hearings on Capitol Hill seem to bring out claims that greenhouse warming has arrived, but published studies have mostly been assiduously ambivalent on the question. For more than a decade, researchers have been debating whether the half-degree of global warming observed so far this century is the signature of humanmade greenhouse gases or some self-correcting climate variation utterly beyond human control. Now two independent studies of the climate record have incriminated the greenhouse effect in global warming, although they fall short of convicting it.

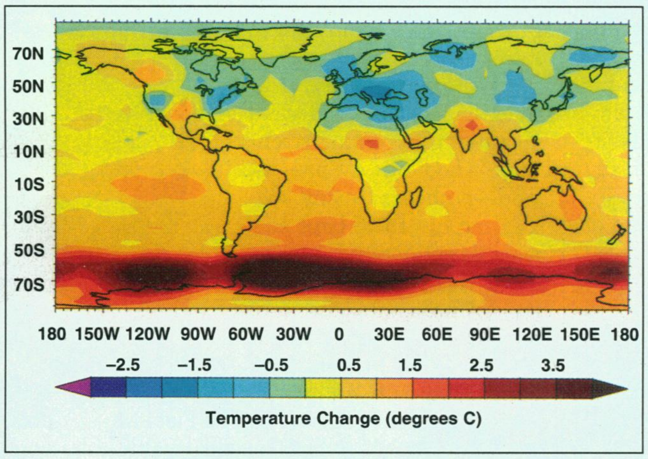
After the most thorough study of its kind to date, researchers at the Max Planck Institute for Meteorology (MPI) in Hamburg are cautiously confident they have exonerated a leading nongreenhouse suspect, natural climatic variability. The observed global warming seems too large, they say in a paper accepted at the *Journal of Climate*, to be caused by climatic give-and-take between the oceans and the atmosphere, which can generate temporary warmings and coolings.

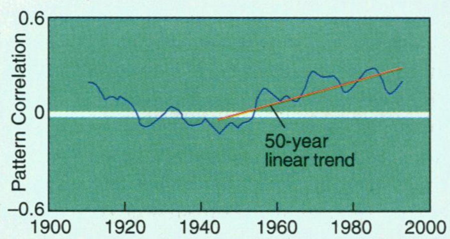
The second group, led by Benjamin Santer of Lawrence Livermore National Laboratory, directly implicates greenhouse warming by finding its geographic "fingerprint" in the climate record of the past century. The trick, the group reports in a paper accepted at *Climate Dynamics*, was accounting for the cooling effect of the humanmade haze that blankets large areas of the Northern Hemisphere. It's the first search for a greenhouse fingerprint to show positive results, says Tim P. Barnett of Scripps Institution of Oceanography. "People have arm-waved, but I believe [Santer] is the first to do a credible job."

Still, Santer says, "I don't want to oversell it. I don't think this is evidence that we've solved the problem; far from it." The caveat goes for both studies, which rely on comparisons between notoriously imperfect computer models of climate and the observed temperature record. "It will take more work to convince everybody," says Thomas Karl of the National Climatic Data Center in Asheville, North Carolina. Still, he adds, "you're seeing a shift in the overall scientific view" toward a greenhouse cause for the warming.

One way to assess the role of the greenhouse effect in the recent warming might be to look into the past and see how climate varies naturally. But records of the real climate are too short for that, so researchers have had to resort to powerful computer simulations of climate. Like an engineer's scale models, these simulations allow researchers to study how the real system behaves—and how it might react to "forcing" from greenhouse gases and other factors.

Gabriele Hegerl of the MPI and her colleagues, including Santer, drew on climate models to understand how climate varies on its own, without any forcing. To get the most realistic picture possible, they used three climate models—one from the Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton, New Jersey, and two from MPI—that simulate not only the atmosphere but also the ocean and its ability to store and transport heat and swap it with the atmosphere. Hegerl and her colleagues compared the decades- and centuries-long variations in surface temperatures seen in runs of these state-of-the-art models lasting as long as 1000 years with the warming recorded over the past century.





Greenhouse fingerprint. In a computer model, a stronger greenhouse combines with hazes to produce a tapestry of warming and cooling *(top)*. The actual temperature record increasingly matches that pattern *(above)*.

The temperature fluctuations in the models consistently fell short of the observed changes. After all the comparisons, Hegerl and her colleagues concluded that there is just one chance in 40 that natural variability is the cause of the global warming of the past 30 years—assuming the models gave them a realistic picture of natural variability. "At the moment there is no other convincing explanation than carbon dioxide for such a big change in temperature," she says. Other climate forcings such as variations in the brightness of the sun seem too weak to explain the warming.

Still, some researchers would like to see more positive evidence for the role of the greenhouse effect in the recent warming. "You can ask a different question" using the climate models, says Santer. "Do the observed [geographic temperature] patterns mimic the patterns we expect from carbon dioxide?"

The first time Santer and his colleagues asked that question, the answer was no. They compared the observed warming pattern with the patterns seen in five different models when they simulated the effects of doubling the carbon dioxide content of the atmosphere. The models indicated that the warming should be most pronounced at high latitudes—where sea ice would melt, making the surface less reflective and amplifying the warming—and in continental interiors. But the observed pattern didn't bear much resemblance to the expected patterns, Santer found, and showed no signs that it was headed that way.

Santer and his colleagues guessed, however, that something was missing from the models, most likely the haze of microscopic particles from industrial emissions that cloaks large parts of North America, Europe, and Southeast Asia. Recent studies have shown that this aerosol haze lowers surface temperatures, presumably by reflecting sunlight back into space and causing clouds to thicken (*Science*, 12 May, p. 802). Regions of aerosol cooling could put big holes in the predicted pattern of warming, they thought, especially in the Northern Hemisphere. So climate modelers Karl Taylor and Joyce Penner of Lawrence Livermore teamed with Santer, Tom M. L. Wigley of the National Center for Atmospheric Research, and Philip Jones of the University of East Anglia to compare the observed record with the temperature pattern seen in climate model runs that simulated the effects of aerosol cooling as well as greenhouse warming.

This time, Santer and his colleagues found a correlation. Starting about 1950, when the growth of carbon dioxide emissions took off, the temperature pattern began to look more and more like that predicted for a combined greenhouse-aerosol effect, at least in summer and fall. That seasonal preference makes sense, says Santer, because those are the months when sunlight is most abundant in the Northern Hemisphere and the reflective haze would have the biggest effect. Santer and his colleagues believe their analysis "supports but does not prove that we have detected ... an anthropogenic climate-change signal."

There are plenty of uncertainties to prompt that tentative note. Taylor and Penner's model isn't state-of-the-art, incorporating only a simplistic ocean. The effects of aerosols on surface temperatures are still uncertain. And, says David Karoly of Monash University in Clayton, Australia, "you could still argue that there are other climate forcings [besides aerosols] that need to be included" in the models. But the biggest reason for caution, Santer and others say, is the possibility that natural variability might be producing a warming that mimics the greenhouse-plus-aerosol signature.

To test this possibility, Santer and his colleagues examined the patterns of temperature change generated by simulated natural variability in 1000-year runs of the GFDL model and an MPI model to see whether they could show the same trend of increasing similarity to the observed record. The comparisons revealed that, depending on the model, there was only a 1% to 3% chance that natural variability was behind the increasing similarity in the summer and fall and about a 6% chance that it was responsible for the similarity in annual temperature trends.

But Karoly says he has "serious concerns as to whether the natural variability [seen in the computer models] is realistic." Indeed, says Santer, doubts about the realism of computer climate models are the biggest hurdle facing both efforts to convict greenhouse warming. Like most climate models, for example, the models in both studies require sizable fudge factors to keep their simulated climates from drifting off into hothouse or deep-freeze conditions for no good reason (*Science*, 9 September 1994, p. 1528).

Uncertainties or no, these two studies do mark a turning point in the search for global warming's culprit. "This is where the debate is really starting," says Barnett. As Karoly puts it, "There's growing evidence [implicating the greenhouse], but it's not incontrovertible. That requires more than one or two studies. We will have to wait."

–Richard A. Kerr

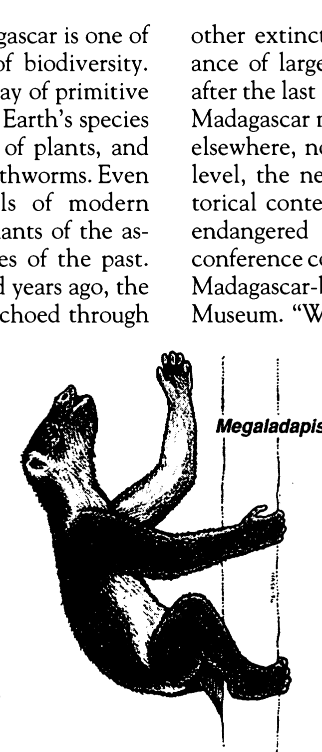
Additional Reading

B. D. Santer *et al.*, *Towards the Detection and Attribution of an Anthropogenic Effect on Climate* (Lawrence Livermore National Laboratory, PCMDI Report No. 21; available from NTIS, 5285 Port Royal Rd., Springfield, VA 22161).

CONSERVATION BIOLOGY

Many Suspects to Blame in Madagascar Extinctions

The tropical island of Madagascar is one of the world's treasure-troves of biodiversity. It's home to a spectacular array of primitive primates, more than half the Earth's species of chameleon, 10,000 kinds of plants, and some of the world's largest earthworms. Even so, the plants and animals of modern Madagascar are merely remnants of the astonishingly rich communities of the past. As recently as a few thousand years ago, the calls of gorilla-sized lemurs echoed through Malagasy forests, while 500-kilogram elephant birds and giant tortoises made a living in the island's complex mosaic of other habitats. By the 17th century, these creatures had all but vanished, creating a perplexing scientific whodunit: What—or who—pushed so many species, most of them large animals, to extinction?



In the past decade, this mystery has spurred droves of researchers to search Madagascar for clues to the culprit. Early this month, an interdisciplinary set of scientific sleuths gathered at The Field Museum in Chicago* to hash out the wealth of new evidence they've accumulated. Many scientists had long assumed that the extinctions were caused by early human populations who colonized Madagascar about 2000 years ago and may have hunted the animals and altered their habitats. But recently a new view has put the onus on a fickle climate, whose natural swings from wet to dry may have squeezed species to extinction.

The view that emerged from the meeting: All of the above were at fault. The new research indicates that natural and human-induced changes both contributed to the extinctions. Moreover, the meeting added yet another suspect to the list, as two researchers proposed the intriguing but unproven idea that humans ferried a lethal pathogen to vulnerable island communities. "It's like *Murder on the Orient Express*," says primatologist Alison Jolly of Princeton University. "The answer is they *all* did it."

Understanding the loss of the Malagasy megafauna may have implications beyond the island itself. The same debate rages about other extinctions, including the disappearance of large mammals in North America after the last Ice Age, and what is learned on Madagascar may shed light on controversies elsewhere, notes Jolly. On a more practical level, the new information provides a historical context for biologists trying to save endangered Malagasy species today, says conference co-organizer Steven Goodman, a Madagascar-based biologist from The Field Museum. "We have to distinguish between human and natural influences on the extinction process in order to understand how to ameliorate the human side," he says.

Any viable Malagasy extinction theory will have to explain the unusual pattern of species loss seen in some of the island's most famous inhabitants: the primitive primates known as lemurs, found almost nowhere else on Earth. Because Madagascar has been isolated from most of the rest of the world's biota for at least 100 million years, it's missing many common taxa, and groups such as lemurs and insectivores evolved into surprising new roles to fill the island's empty ecological niches. For example, some lemurs evolved slothlike adaptations, eating leaves and slowly swinging through trees; another species with huge feet and toes clambered through the trees "something like a giant koala," says William Jungers of the State University of New York, Stony Brook. A few thousand years ago, 49 known lemur species inhabited the island. Today, only 32 species survive.

Anthropologists have found a noteworthy difference between the living lemurs and those who died out: All the big animals—those weighing more than 10 kilograms—went extinct, says Laurie Godfrey of the University of Massachusetts, Amherst. She showed that the living species represent only a small, selected slice of the past ecological diversity. Living lemurs are mostly forest-dwelling agile leapers, while the giant extinct species tended to be slow-moving climbers. And although many modern lemurs are nocturnal, Godfrey and co-workers think most extinct lemurs were diurnal.

The selective extinction of large, slow, diurnal primates raises the obvious possibility that human hunters were the culprits, says primatologist Elwyn Simons of Duke Uni-

*The meeting, entitled "Natural and Human-Induced Change in Madagascar," was held from 2 to 4 June.