line segments connecting a set of points in a plane, much as the interstate highway system connects U.S. cities. The geometric problem is to find the shortest possible network for a given set of points. Somewhat surprisingly, the entire network can sometimes be shortened by adding extra points.

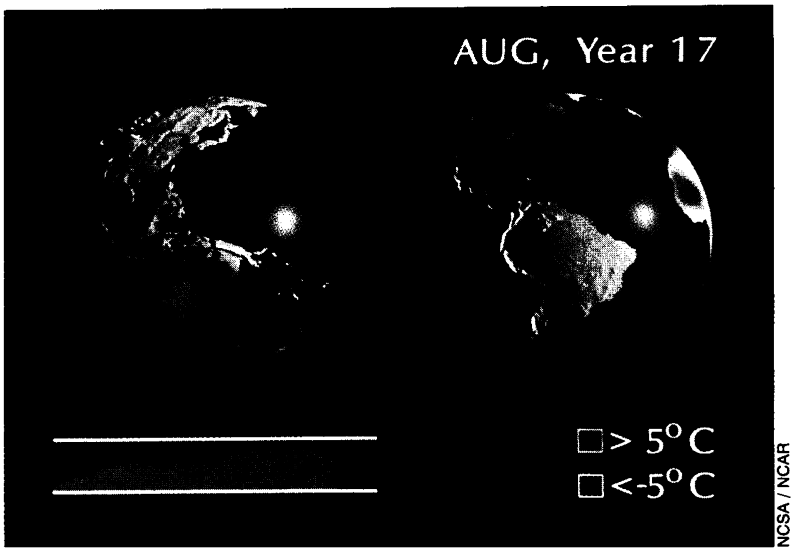
For example, the shortest highway system connecting Kansas City, San Diego, and Seattle consists of a 1700-mile road from Kansas City to San Diego and a 1300-mile segment from San Diego to Seattle. But if Salt Lake City is added as a hub, the total becomes: 1150 miles from Salt Lake to Kansas City, 800 to San Diego, and 900 to Seattle, for a total of 2850, or 5% less than the original total of 3000.

That's interesting, but specific. What, in a more general sense, is the most that can be saved by adding points? For three points, the greatest savings are achieved when the points are at the vertices of an equilateral triangle. In that case, using the center of the triangle as a hub reduces the length of the network by a factor of $\sqrt{3}/2$—a saving of some 13%. The saving is the same for a larger network when the points lie in an equilateral zigzag pattern. But is there a pattern that allows for a savings of more than 13%? Hwang and Du now provide the answer: No.

That negative rejoinder had been conjectured in 1968 by Edgar Gilbert and Henry Pollak of Bell Laboratories. Subsequent work (including some by Hwang and Du) verified their conjecture for systems including four, five, and six points. But then the attack bogged down. Further assaults—relying on messy computations—showed that the maximum savings couldn't be more than 18%. But there the effort stalled, although mathematicians still had the uneasy feeling that the Gilbert-Pollak conjecture was correct.

By contrast, Hwang and Du's proof is "conceptual in nature and requires essentially no computation," says Hwang. Their proof takes a totally new approach. It begins by formulating the initial conjecture as a "minimax" problem—a type of problem in game theory in which one player seeks to minimize the payoff available to the opponent. In the minimax version of the problem, it can be shown that any counterexample to the conjecture must take the form of points spaced in a regular, equilateral fashion. The proof now shows that the conjecture holds when the points are spaced that way.

Hwang and Du are looking beyond the network problem to a number of other mathematical optimization problems to which the new approach could be applied, but that "so far we haven't really seen an immediate application." Maybe they should take a look at the Federal budget. ■ BARRY CIPRA



The right greenhouse model? *This climate simulation for Earth under doubled carbon dioxide is uncertain by several crucial degrees.*

Climatologists Debate How to Model the World

Will global warming be modest or catastrophic? The White House is pushing an initiative to help find out

THE BUSH ADMINISTRATION IS PUTTING together a proposal for an ambitious national program to develop a new generation of supermodels of the world's climate. The goal: to get a better fix not just on how warm the climate of the 21st century will be but how specific areas of the globe—the U.S. breadbasket, for example—will fare in the greenhouse world.

Initial funds for the venture are expected to be included in the budget the White House will send to Congress early next year—if a committee of the Office of Science and Technology Policy, which is managing the effort, can come up with a plan acceptable to the climate modeling community. The community has already balked at two draft proposals that would have used an Apollo-style approach to produce a single climate model. Instead, the effort is likely to generate several competing models, each built upon the contributions of researchers at many institutions. It will be no small task, and it should take a decade to accomplish. Computer speeds will have to increase by a factor of 10,000 over those of current machines, a major observation program will be needed to gather data to plug into the models, and a lot of fresh talent will be required to piece it all together.

There's little argument that better climate models are needed. In 1979, a committee of the National Academy of Sciences under pioneer meteorologist Jule Charney estimated that a doubling of carbon dioxide in the atmosphere would cause anything from a modest 1.5°C global warming to a 4.5°C catastrophe. And the current models are still coming up with the same awkwardly broad range.

A major problem facing the modelers is that they do not understand how the real world works well enough to tell a model how to simulate climate realistically. For example, how does a high, icy cirrus cloud reflect incoming and outgoing radiation compared with low, thick stratus clouds? The answer could make all the difference to predictions of global warming, so researchers want more field studies of clouds—not to mention plants, soils, oceans, and myriad other participants in the shaping of climate. Current models, moreover, can predict climate changes only for large areas; they lack the data and computing power to gauge how temperature and rainfall might change in a small region, such as the Iowa cornfields.

The new modeling initiative has been in the works since the U.S. Global Change Research Program was launched as a Presidential initiative 3 years ago. By early this year, that program had elicited two competing proposals for organizing a national model development effort. Both were sharply criticized by climate researchers for being too narrowly focused.

The first entry, the Computer Hardware, Advanced Mathematics and Model Physics (CHAMMP) Climate Modeling Program was proposed by the Department of Energy last March. To critics like Jerry D. Mahlman, director of the National Oceanic and Atmospheric Administration's (NOAA's) Geophysical Fluid Dynamics Laboratory (GFDL) in Princeton, New Jersey, it smacked of too much engineering and too little science. It concentrated on computer technology, relying heavily on talent in the national labs, to create a single national climate model.

Much of the needed improvement in number-crunching capability, according to the CHAMMP proposal, would come by shifting from today's workhorse, the Cray Y-MP with eight processors, to computers with thousands of microprocessor chips working simultaneously. That approach could provide speeds 10,000 times greater than that of the Cray.

CHAMMP's competitor, the Climate System Modeling Program (CSMP), was proposed by the University Corporation for Atmospheric Research, the consortium of universities that runs the National Center for Atmospheric Research (NCAR) for the National Science Foundation. Though the first circulated draft concentrated more on science, it also adopted a highly centralized approach. In that version, different groups would build separate modules that would be slapped into a definitive model, the way the atom bomb was built within the Manhattan Project. "That's a flawed concept," Mahlman says. "What you need is independent groups coming up with independent bright ideas and making independent mistakes."

CSMP's new scientific director, Francis Bretherton of the University of Wisconsin, recently circulated a revised version of the plan that has gained more support. It focuses less on building the ultimate supermodel, concentrating instead on plugging some of the scientific gaps—how clouds behave, how the ocean takes up carbon dioxide, how the geologic record can be used to test a model's performance.

Elements of both proposals are likely to form part of the final initiative. But even the organizers of CSMP and CHAMMP now agree that the goal is to produce not one but several competing models. Seeing how widely models differ "gives us an idea of how much we don't know," says modeler Gerald North of Texas A&M. "If there were only one climate model, we would tend to believe it. That would be a big mistake."

The new effort is expected to build upon existing models that have been developed at several U.S. centers such as NCAR, GFDL, and NASA's Goddard Institute for Space Studies in New York City. Michael Hall, who runs the global change office at NOAA, says he expects the final proposal will entail a mix of centralized modeling activities at such centers and distributed research that helps feed those efforts. "To centralize [to a single model] at the expense of these centers in the United States would be foolish," he says. "The richness of our diverse approach to science is one of our strengths."

The modeling work is also likely to be spread over several different agencies. "Given the challenges of Earth-systems modeling, no one agency can do it," says Ari Patrinos, acting director of DOE's Atmospheric and Climate Research Division. "It can't be a NOAA or NASA or DOE model. It has to be more of an integrated model, or several models." And other agencies will be feeding new data and scientific understanding into the models. NOAA, for example, is likely to get some additional funds to enhance its long-term monitoring of climate; it has already launched a $12-million initiative to create centers at which model results and relevant observational data could be analyzed in greater depth than is now routine.

Knitting all this together into a coherent program will be up to an unusual federal group recently renamed the Committee on Earth and Environmental Sciences, or CEES. It was established about 3 years ago as an arm of the White House's Office of Science and Technology Policy through which federal agencies such as NOAA, NASA, NSF, and others could not only coordinate but actually integrate their global change programs.

The committee is a novel departure from the traditional way of doing things in Washington. Usually, individual agencies pitch their own programs to the Office of Management and Budget. But under CEES, science priorities in global change research are first sorted out among the agencies and then presented as a budget package to OMB. The committee has already had an impact: A seven-agency program for all of global change, not just modeling, garnered a fiscal year 1991 request of more than $1 billion, up from $0.5 billion the year before.

Even so, some researchers worry that a surge in funding and faster computers still won't be enough to improve markedly on Charney's 10-year-old estimates. "It is a problem that is so quantitatively difficult," says Mahlman, "that throwing money around is not going to solve it by 1999 or whenever. It is a problem that is fundamentally limited by talent." A well-funded initiative may, however, be just what's needed to draw new talent into the field.

■ Richard A. Kerr

The European Greenhouse World

While American researchers consider how to develop the next generation of climate models, their colleagues across the Atlantic have already decided on several loosely coordinated national efforts to develop independent models. The new Hadley Center for Climate Prediction and Research in Bracknell, England, has a staff of 100, including more than 20 Ph.D.'s, and an annual budget of roughly $20 million, according to David Bennett, the center's research coordinator. That places it in the ranks of the National Center for Atmospheric Research and NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), but Hadley has something no U.S. center has: a supercomputer dedicated to modeling climate on decadal time scales. It is now a somewhat antiquated Cyber 205, but by spring it will be a state-of-the-art supercomputer.

The effort at the Hadley Center probably equals the long-term climate modeling work in the rest of Europe combined, but the Max Planck Institute in Hamburg has impressed American visitors in several areas—especially its model ocean. It is the first used in climate modeling that is not simply a direct offspring of GFDL's. The institute's Ulrich Cubasch explains that decadal modelers there have half of a Cray 2, which is 1985 technology, at their disposal. By the end of the year, says Cubasch, the Max Planck climate model will have been run 100 years into the future three times to predict the greenhouse warming. One run will be driven by an instantaneous doubling of atmospheric carbon dioxide and two runs will involve different scenarios of increasing carbon dioxide. Only two such transient model runs have ever been published, one from GFDL and one from NCAR, and they are still far from agreement.

Given these and other independent-minded centers, the Europeans as a group have taken a multiple-focus approach toward predicting the climate of the 21st century. Within a European Community project called Epoch, participating countries will receive EC funds to the extent that they collaborate within the EC. The Max Planck Institute will be the coordinating center. It appears that at least three major models will result—Max Planck's, Hadley's, and one from the French, who have recently pulled together disparate programs from around the country. ■ R.A.K.