Mogi of Tokyo University. The 1984 Round Valley and July's Chalfant earthquakes have since filled in more of the White Mountains pattern. A similar Mogi doughnut, as the pattern is called, appeared in the 5 years preceding the magnitude 6.8 Coalinga, California, earthquake of 1983.

A Mogi doughnut encircling a seismic gap is intriguing enough that seismologists would not be at all surprised if a large earthquake of magnitude 7 or almost 8 struck anytime within the next few years or a decade. Adding a curious twist to such forecasts is a stunning if deeply mysterious regularity in the seismic activity near the gap. In December 1984 Ryall and David Hill of the USGS in Menlo Park pointed out that the recent Round Valley earthquake was the fifth in a sequence of earthquakes that had struck every 18 months since October 1978. A simple linear extrapolation made later by James Savage of the USGS in Menlo Park called for the next significant event in the sequence, if there were one, to occur on 27 March 1986. The Chalfant swarm struck on 20–21 July, 4 months "late." Savage has now extrapolated from the six events, none of which falls more than 3 months from a single straight line, and found that the next event in such a sequence would be 7 December 1987.

This extrapolation "is not intended as a prediction," says Savage, "I don't quite believe it myself." The problem is that the only place where repetitive activity occurs that even approaches such regularity is at one spot near Parkfield on the San Andreas. Moderate earthquakes recur there about every 22 years and magnitude 3 shocks recur every 39 to 41 months. But the events of the White Mountains sequence fall on a different fault each time, making the driving mechanism of the apparent periodicity obscure indeed.

The Chalfant event "confirms the periodicity," says Savage, "but what the sequence says beyond that I don't know. If it occurred on one fault, it would be easier to understand." Asked if the next moderate shock in the sequence might trigger the large quake, Hill concedes that, mysterious or not, "as the next interval comes up, it will be hard to ignore that straight line."

The prospect of a large earthquake in the near future will not likely divert much attention to the White Mountains gap. The USGS is already heavily committed to monitoring the San Andreas, Parkfield, and nearby Long Valley, a quiescent volcanic caldera that forms part of the doughnut and had threatened to reawaken. The concepts of seismic gaps and doughnuts are rather well worked out in the case of earthquakes occurring between plates, but the White Mountains area is a geologically complex zone within a plate that is riddled with a variety of fault types. And, because of the emptiness of the land, even a large shock will not do much more damage than the Chalfant quakes. ■

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Washington Embraces Global Earth Sciences

For reasons of science and for reasons of strategy, the funding agencies want to study the earth as an integrated whole

On the face of it, deficit-haunted Washington is not the most promising place to be promoting a visionary new research program. And yet, just within the past year or two, a rare combination of scientific urgency and bureaucratic self-interest has led the funding agencies to embrace what may well be the largest cooperative endeavor in the history of science.

The proposal goes under a variety of names, including Global Geosciences at the National Science Foundation (NSF), Earth Systems Science at the National Aeronautics and Space Administration (NASA), and the International Geosphere-Biosphere Program at the National Academy of Sciences. But each name expresses the same fundamental idea: a simultaneous study of the climate, the oceans, the biosphere, the dynamics of the solid earth, and the biogeochemical cycles of all the major nutrients—in short, a study of the earth as an integrated whole. This study will in turn require a permanent network of satellites in orbit and another network of instruments on the ground, all feeding data into state-of-the-art computers. It will involve cooperation among earth scientists from every part of the world. And it will somehow have to be sustained for decades.

Obviously, a project of this magnitude will be neither cheap nor easy to bring off. But the enthusiasm for it seems infectious nonetheless. "[The global research program] is an idea whose time has come," says National Oceanic and Atmospheric Administration (NOAA) Administrator Anthony J. Calio. "It symbolizes the realization that a complex industrial society is vulnerable to environmental change. It symbolizes the realization that a comprehensive, global approach to understanding that change is better than ad hoc alarms over problems such as carbon dioxide buildup, ozone depletion, and acid rain. And it symbolizes the consensus that this is what we ought to be doing."

Big, international programs are hardly a new idea, of course. The global research effort is very much in the tradition of the International Geophysical Year of 1957–58, as well as such modern heirs as the Global Atmospheric Research Program. As Calio suggests, however, the past decade or so has only served to dramatize the need for a truly comprehensive program. Humans are beginning to perturb the climate and the biosphere on a planetary scale. Governments are being faced with dire warnings and controversial policy decisions. And yet the gaps in our scientific knowledge of the system are enormous. Carbon dioxide, ozone, the global climate—all are governed by processes that take place on a time scale of decades to centuries; one cannot understand them without also understanding a great deal more than we do about oceans, rain forests, ice sheets, volcanic activity, and all the interconnections among them.

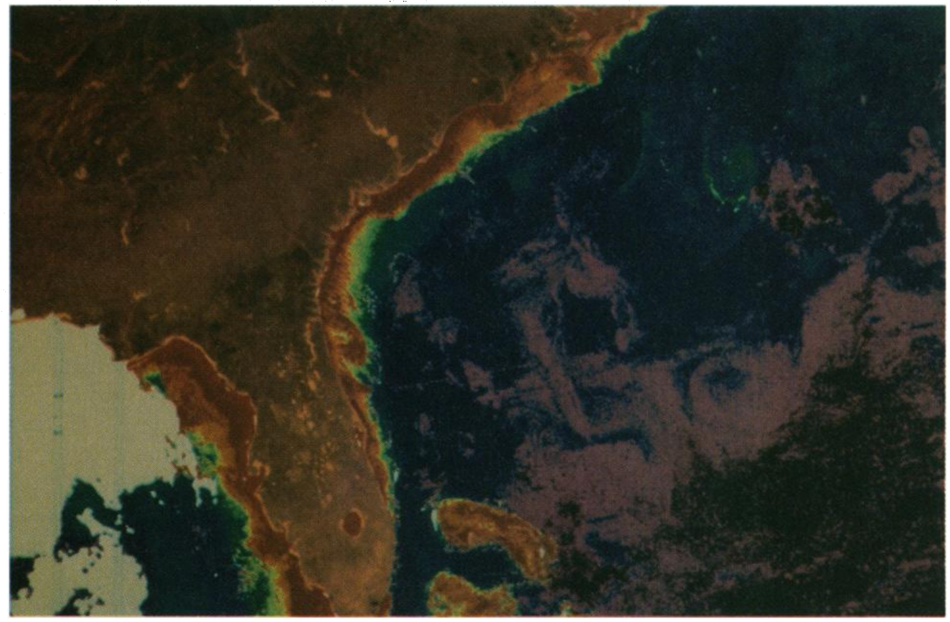
The result has been what John Eddy of the University Corporation for Atmospheric Research in Boulder, Colorado, calls "a spontaneous ecumenical movement" among earth scientists. By the early 1980's, calls for a comprehensive global research program were being heard from a number of quarters, with two of the most notable being NASA's 1982 proposal for a "Global Habitability" project, and the 1983 suggestion by Herbert Friedman of the National Academy that the nations of the world cooperate on an International Geosphere-Biosphere project. More recently, this ecumenical movement has also taken hold among the federal science agencies. The NSF has already made global research the centerpiece of its earth sciences program. In October 1985, meanwhile, the White House Office of Science and Technology Policy issued a report urging that global remote sensing be established as a key goal of the U.S. space program. In May that call was renewed in the report of the National Commission on Space, and in June it was renewed again with the report of NASA's Earth Systems Science Committee. Finally, the National Academy released a report this spring identifying priorities for an international program. That report in turn is part of a 2-year study chartered by the International Council of Scientific Unions in 1984; this September the council's general assembly is expected to endorse just such an international program for the 1990's.

Paradoxically, the global research program is both visionary and relatively modest at the same time, in the sense that it will not require an immediate quantum leap in funding. "Many of the observations we need are already being made for other reasons, such as weather forecasting," says Francis P. Bretherton of the National Center for Atmospheric Research, who chairs NASA's Earth Systems Science Committee. "It's more an attitude of mind. We want to make sure that we go the extra mile—that we cover everything."

That attitude is very much in evidence in the report that Bretherton and his colleagues delivered to NASA on 26 June. The committee was originally chartered in 1983 and given the task of fleshing out the agency's Global Habitability proposal; what it eventually produced was perhaps the most comprehensive plan for a global research program to date, including detailed recommendations on the roles of NASA, NOAA, NSF, and a number of other agencies. As Bretherton has pointed out many times, it makes no sense to look at NASA in isolation. Satellites and ground-based sensors are simply two complementary ways of gathering data; they do not represent two different kinds of science.

The Bretherton report was produced in close collaboration with the staffs of the relevant agencies, and thus has been warmly received all around. Indeed, one of the striking things about the global research program is the lack of any major turf fights; the traditional agency lines make for a natural division of labor.

NASA, of course, has primary responsibility for earth sciences research missions from space, as well as for the development of advanced sensors and improved data-handling techniques. The Bretherton committee foresees two distinct eras in this part of the program. For the near term, it says, NASA should continue to emphasize specialized missions such as TOPEX, the Ocean Topography Experiment, or UARS, the Upper Atmosphere Research Satellite, which have already been planned. These missions should be well under way by the mid-1990's.



Ocean color from space. *This satellite image has been computer-enhanced to highlight the distribution of chlorophyll in the ocean. The most intense reds correspond to the regions of greatest biological productivity.*

For the mid-1990's and beyond, however, the committee urges NASA to continue with its plans to build one or more advanced instrument platforms in polar orbit. The polar platform is officially part of NASA's space station project. But in effect, it will be a major new space observatory on the scale of the Hubble Space Telescope, and a central component of the global research program. It will be permanent in the sense that it will be serviced and upgraded on a regular basis by space shuttle crews. It will also offer accommodation for many instruments simultaneously. For example, NASA and NOAA are jointly studying one polar platform package—the Earth Observing System, or EOS—that would include one group of instruments to image the earth at visible, infrared, and microwave wavelengths; a second group to study the surface using radar; and a third group to study the composition and dynamics of the atmosphere.

According to NASA's Office of Space Science and Applications, NASA's portion of the global research program could be accommodated within an earth observations budget about 25% higher than its current level of $300 million to $400 million per year. (That estimate does not count the cost of the polar platform itself, since NASA was planning to build it anyway.) Of course, it is not clear when—or if—this new money will be forthcoming, especially when one considers that the agency is still trying to come to some kind of equilibrium in the wake of the Challenger accident. Nonetheless, NASA Administrator James C. Fletcher has gone out of his way to express support for a global program, privately as well as publicly. Staffers at the working level thus seem willing to be patient. "What comes out of the budget process this year may not be a good test of our commitment," says Dixon Butler, program scientist for the Earth Observing System. "The earth systems idea has already taken hold here intellectually. It dominates all our thinking. But I'd say it will be about 4 years before we see how effectively it has taken hold in monetary terms."

Meanwhile, just as NASA has a natural role in space observations, NSF has an equally natural role in doing global research on the ground, in the air, and at sea. Its new Global Geosciences initiative is in fact a commitment to do just that. "The community has developed a consensus on this in an astonishingly short time," says William J. Merrell, head of the agency's Geosciences directorate. "You quickly realize that you can't study one piece of the problem in the 1970's, another piece in the 1980's, another piece in the 1990's, and hope to fit it all together. It just won't work. The scientific problem demands that you look at everything simultaneously."

From a programmatic standpoint, of

course, Global Geosciences also provides Merrell and his colleagues with a framework for setting priorities and allocating their limited resources in the era of Gramm-Rudman-Hollings. The program only emerged as an explicit NSF initiative last year, as the Geosciences staff was preparing its fiscal year 1987 budget proposal. But NSF director Erich Bloch was more than willing to go along: he set the first year's budget request for Global Geosciences at $18.3 million, which was the largest figure that the geosciences division itself had asked for.

As currently structured, Global Geosciences comprises seven separate programs of study, ranging from global tropospheric chemistry to the dynamics of the solid earth. "Each of these areas already has some ongoing activities," explains Nancy Ann Brewster, Merrell's assistant for policy and planning. "What we're doing in Global Geosciences is repackaging the existing programs and expanding their scope and budgets." In fiscal year 1988, for example, the agency hopes to add glaciology and a study of paleoclimates to the program.

In the spirit of the Bretherton report, Global Geosciences will also involve extensive participation by NASA, NOAA, the U.S. Geological Survey, and other agencies. The coupling of field programs with remote sensing data will be particularly important, says Brewster. Because of the long lead time required to fund and launch satellites—a lead time that exists quite independently of the Challenger disaster—the NSF initiative will focus on in situ science for the next 5 years or more. "But when the satellites do fly," she says, "many of our field programs will go into an intensive observational phase closely keyed to the satellite observations; we'll be validating and calibrating the satellite data with ground truth."

"Eventually," she adds, "what we hope for is an entire earth-observing network, integrating everything from the polar platform to the ships and ground stations."

Finally, there is NOAA, a deeply troubled agency that nonetheless stands to play a pivotal role in the global research program.

Whereas NASA and NSF are primarily set up to do path-breaking research, the global program is also going to require the systematic collection of data on a time scale of decades, so that scientists can look for long-term cycles and trends. NOAA, which has charge of the weather service, is already set up to do just that. Indeed, its archives include climate records going back a century or more and have provided an invaluable resource for modern climatologists. More recently, its routine satellite imagery has proved to be surprisingly useful for mapping drought and/or agricultural productivity across entire continents. In short, NOAA is the natural agency to take the lead in collecting, archiving, and disseminating a systematic data base on the global environment.

Unfortunately, NOAA is also in a chronically weak political position. As a subagency within Department of Commerce, it has never had an independent voice in Washington. And under the Reagan Administration it has constantly been the subject of a fiscal tug-of-war. Every year, the White House Office of Management and Budget removes a host of NOAA programs such as Sea Grant, and every year Congress puts them back in. Every year, the White House attempts to cut NOAA back to one polar orbiting weather satellite instead of two, and every year Congress puts it back in. This year, the White House reneged on an agreement to provide seed money for Landsat commercialization, an agreement that NOAA, Congress, and EOSAT, the private Landsat operator, had spent years hammering out. Congress is now in the process of putting the money back in.

If any major science project stands a chance of prospering in the Gramm-Rudman-Hollings era, it is this one.

Given all that—not to mention the specter of Gramm-Rudman-Hollings—it is perhaps not surprising that NOAA has enthusiastically embraced the global research program as a way of strengthening its rationale and purpose. "When you think about it, NOAA is essentially an information agency," says William Bishop, head of NOAA's satellite and information service. "We collect the global data set on the environment. So far, that data has been mostly for purposes of forecast and warning. But to me, the scientific community is just as legitimate a customer for that routine data as the TV stations." Of course, he adds, science represents a different kind of customer. "A scientist has to be able to compare data over a decade or more to look for trends, which puts demands on calibration, record-keeping, and continuity that just aren't there when you focus on day-to-day prediction. It's something that we at NOAA have had difficulty stepping up to. And yet the message we get from all over Washington is that this is a *very* good charter for NOAA."

Thus, as best it can, NOAA is beginning to move in this direction. For example, in the fiscal year 1988 budget, which will be submitted to Congress in January, Bishop hopes to include two initiatives designed to open up NOAA's vast data bases to outside researchers. The first, NOAAPORT, will provide access to the real-time data used for forecasting—everything from satellite cloud imagery to global wind field measurements. One concept for doing this would be to broadcast the data from a satellite in geosynchronous orbit so that it could be picked up anywhere with an inexpensive ground station.

The second initiative, NOAANET, will be a network providing access to NOAA's long-term archival data, much of which will be made available in digital form for instant access.

Looking into the next decade, meanwhile, NOAA officials are even more enthusiastic about the polar platform than their counterparts at NASA. Among other things, the platform offers them the opportunity of consolidating their instruments on a permanent facility, where they can be replaced and upgraded as needed. Thus, they will no longer have to launch a whole new spacecraft every time one or two instruments fail.

Of course, it is certainly possible to be a skeptic about all this. NOAA continues to be in a weak position, and given the budgetary constraints, it is not at all clear that favorable words about global research will be translated into funding. NASA is still embroiled in the aftermath of the Challenger disaster, and it looks as if the space station program—along with the polar platform—may very well be delayed.

And yet, this vision of a global research program has clearly taken hold, both in the scientific community and at the working levels of the funding agencies. Furthermore, for once people are pulling together at the interagency level. As Calio points out, "The deficit reduction efforts are forcing us to work more closely together."

Indeed, if any major science project stands a chance of prospering in the Gramm-Rudman-Hollings era, it is this one—simply because everyone involved has a stake in making it work. ■

M. Mitchell Waldrop

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