An Inquiry into the State of the Earth

Technology is making it possible to study the earth as an integrated system; problems like ozone and acid rain are making it imperative

Quietly, but ever more forcefully, momentum is building for the largest cooperative endeavor in the history of science: a study of the earth and its environs as an integrated whole.

The International Geosphere-Biosphere Program (IGBP), as it is known, would encompass the global climate, the biosphere, and the biogeochemical cycles of all the major nutrients. It might well include the pulsations of the sun and the tectonic processes in the core of the earth. It would take data from satellites in orbit and instruments on the ground. It would involve a sharing of effort among scientists from every part of the world. And it would somehow have to be sustained for decades.

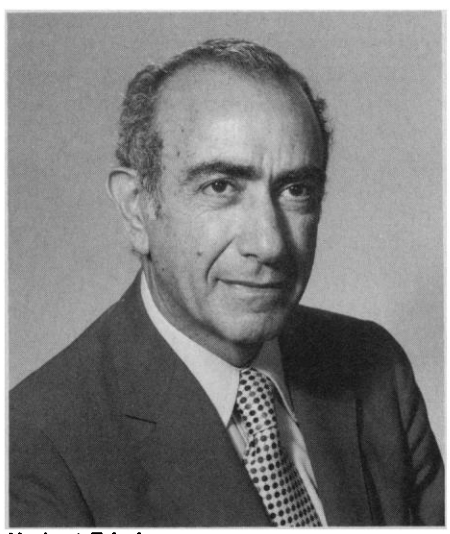
The obstacles, both economic and political, are clearly horrendous. But the enthusiasm within the scientific community is growing nonetheless. The International Council of Scientific Unions, meeting in Ottawa, has just endorsed a 2-year study to draw up a detailed plan for the IGBP. And in the United States, the National Academy of Sciences is also formulating a detailed plan in conjunction with the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), the National Oceanic and Atmospheric Administration (NOAA), and a host of other agencies. By 1986, the IGBP could be ready to move.

There is nothing new about big, international programs, of course. The IGBP is very much in the tradition of the International Geophysical Year (IGY) of 1957–58, as well as such modern heirs of the IGY as the World Climate Program or the International Biological Program.

During the last decade, however, issues such as ozone depletion, carbon dioxide buildup, and now acid rain have dramatized the need for a truly global program. Humans are beginning to perturb the climate and the biosphere on a planetary scale, and yet there are enormous gaps in our knowledge of the system: governments have been faced with making expensive and controversial policy decisions on the basis of scientific guesswork.

"The picture now is full of programs that are competitive with each other and ad hoc," says Herbert Friedman, chairman of the National Academy's Commission on Physical Sciences, Mathematics, and Natural Resources, and one of the originators of the IGBP idea. The existing programs also tend to be of limited duration, even though many global processes take place on a time scale of decades or centuries. "You cannot address these questions without 10 to 20 years of rigorous research," he says.

So the IGBP would both complement the existing international programs and



Herbert Friedman

go beyond them, says Friedman. Instead of following the traditional division of the earth into atmosphere, lithosphere, and oceans, the IGBP will try to look at processes in a more holistic framework. In particular, it will lay a much greater stress on biology and chemistry, especially the biogeochemical cycles of such key nutrients as carbon, nitrogen, sulfur, and phosphorus.

As an example, consider the problem of methane, CH_4, a natural product of bacterial fermentation and the digestive processes of certain ruminants. Methane is a trace gas in the atmosphere, with a concentration of about two parts per million. During the last decade, however, its concentration has been rising at a comparatively enormous rate, roughly 1 to 2 percent per year. No one knows why. A larger population of cattle, perhaps? Increased cultivation of crops such as rice, which grow in waterlogged fields?

The rise has to be understood, however, because methane, like carbon dioxide, is a greenhouse gas and could thus have a significant effect on the climate. In the stratosphere, methane interacts strongly with chlorine radicals liberated from halocarbons and thus has an indirect effect on stratospheric ozone. In the troposphere, it is a controlling factor in the concentration of the hydroxyl radical, OH, which is itself a key to such things as smog and ozone formation.

A second reason for the sudden interest in an IGBP is technological: rapid advances in computers and the relative maturity of remote sensing have just begun to make the effort possible.

Only in the last decade, for example, have the sensors been available to give synoptic, large-scale views of the earth from space. NASA's Landsat series, begun in 1972, pioneered in geological surveys and the monitoring of crops and snow cover. The infrared instrument on NOAA's polar-orbiting weather satellites is being used to compile weekly maps of a "vegetation index," which dramatically illustrate the march of the seasons across the continents. In 1978 NASA's Seasat measured winds and wave heights over most of the world's oceans. An Upper Atmosphere Research Satellite, scheduled for the late 1980's, will monitor the chemistry and physics of the stratosphere and mesophere. And the list goes on.

Meanwhile, computers are critical for testing geophysical theories with ever more sophisticated and complex models, and also for handling the shear mass of data. The Landsat-5 satellite is already threatening to swamp the available computers with some 85 million bits of image data per second; the output of a global, multi-decade IGBP would be staggering. One of the earliest challenges in the program will be to set up an international data archive, using the most advanced computer techniques available.

A final reason that IGBP is gaining ground, and in some ways the most important reason, is that the idea has acquired some strong champions.

At the National Academy of Sciences,

the inspiration came in 1983 from Friedman, who had been a participant in the International Geophysical Year of 1957–58. "I thought that, rather than simply celebrate the 25th anniversary of the IGY, why not see what we could do with new techniques?" he says. He was also concerned at the deepening chill in U.S.-Soviet relations: "All the international cooperation and communication that had come out of the IGY seemed to be fading. I thought we might be able to revive some of that."

An early convert was Thomas F. Malone of Resources for the Future, past foreign secretary of the academy and a veteran of the Global Atmospheric Research Program. Like Friedman, Malone was convinced that IGBP would not work as a genuine international effort unless it was coordinated by the International Council of Scientific Unions, ICSU, the same body that had been responsible for the IGY. Malone has thus spent a good part of the past year in airplanes.

"People ask me why I'm doing this at my age," says Malone, "and I tell them it's because I have ten grandchildren and two more on the way." The overseas response to IGBP has been remarkable, he says. "I was particularly heartened by discussions in Beijing and Moscow, where I found a high degree of interest, not only from the academicians, but from the scientists in the trenches."

Still, he says, things do have to move at their own pace. On 25 September, at ICSU's request, Malone and Juan G. Roederer of the University of Alaska conducted a symposium on the IGBP at the ICSU General Assembly in Ottawa. The following day ICSU approved the next phase: a 2-year sequence of workshops that, if successful, will result in a multinational plan for implementing IGBP. If that plan is approved in turn by the next ICSU general assembly in 1986, says Malone, an international coordinating committee will be formed, and the IGBP will move forward in much the same way as the IGY.

Meanwhile, in parallel with the ICSU effort, an academy committee under John A. Eddy of the National Center for Atmospheric Research has begun to design a set of sharply focused initiatives for the IGBP. In effect, Eddy's group is organizing a U.S. national plan. "We're not looking for IGBP to be a big, unwieldy umbrella program," says Friedman. "What we need is a limited set of high-priority thrusts around which a long-range program can grow." The committee is expected to report within the next few months.

About a year before the IGBP, NASA launched an independent, but very similar, "Global Habitability" program. It was originally conceived one Saturday in February 1982 in an all-day bull session between NASA associate administrator Hans Mark, now chancellor of the University of Texas, and Harvard University geophysicists Richard Goody and Michael McElroy. The idea was to take a good look at the factors affecting the earth's ability to support life, primarily the biogeochemical cycles and the climate; as Mark cheerfully admits, he needed a way to bring coherence and focus to the agency's Earth observations program—and to protect it against the Reagan Administration's budget cuts.

"The problems are so big that the United States simply cannot do it alone."

Unfortunately, NASA went public with Global Habitability long before it was ready. In August 1982 NASA administrator James M. Beggs presented the still-embryonic concept to UNISPACE, the United Nations space conference in Vienna (*Science*, 21 September 1982, p. 916). Somehow, the message came across as "Here's what NASA's going to do. Join us."

The reviews were scathing. In Vienna, third-world delegates were insulted at the implied condescension, and worse, members of the international science bureaucracy saw Global Habitability as undermining the existing global programs, which had gotten under way only after years of painful effort. Back in Washington, Global Habitability looked like an attempt to grab turf away from NSF, NOAA, and the other science agencies.

The upshot was that NASA hurriedly backed off, and by fall of 1982 Global Habitability had a very low profile.

It was far from dead, however. For one thing, the scientific merits of Global Habitability were undeniable, and a lot of scientists were endorsing it. For another, there was something about it that had a way of turning skeptics into enthusiasts. "When Global Habitability first crossed our path we all said 'Terrible idea,' " says one convert. "But when you actually looked at it, it was a very good idea—just packaged terribly."

Finally, Global Habitability kept going because NASA officials at the working level kept fighting for it as an *inter*agency program. In particular, they welcomed the National Academy's IGBP initiative. "We're extremely supportive," says Robert Watson of NASA's earth observations division. There are still no formal ties, he adds, "But many of us view IGBP as *the* right vehicle for making Global Habitability an international program."

All this sounds very rosy. But, of course, IGBP still faces a host of unresolved issues. For example:

• Scientific scope. The processes affecting the earth fall naturally into three groups, with relatively weak couplings between them: solid earth geophysics, solar-terrestrial interactions, and climate/biosphere/chemical cycles. The latter group dominates the environment on the 10- to 100-year time scales and it practically defines the NASA Global Habitability program. Many scientists think that IGBP ought to concentrate its efforts in this area, if for no other reason than practicality.

But Friedman, for one, still thinks that the IGBP ought to look at the interactions as broadly as possible, especially since many of those "weak" couplings seem to have profound effects. On a million-year time scale, he points out, the chemistry of the ocean is dominated by hydrothermal action at the mid-ocean ridges. Even on a 100-year time scale, variations in the sunspot cycle are correlated with "little ice ages" on Earth.

• Credibility, especially in the Third World. It is one thing to trade weather data, which everyone does quite freely. But people get very sensitive when someone else starts looking at, say, their crop yields. If IGBP ever suffers the slightest taint of being a front for military intelligence or for economic exploitation, it will be in serious trouble.

On the other hand, says Friedman, one of the attractive things about IGBP is that it gives Third World nations a membership card into top-notch science. "Some awfully important things can be done very simply," he says. "Measuring sea level, for example. It doesn't cost much, but the records have to be accurate and they have to be kept over a very long time, so that we can tell if the sea level is changing."

• Institutional framework. Friedman, a man in his late 60's, talks calmly about a program that will not hit its stride until 1995, and that will not return some of its most interesting data for 20, 40, or 50 years after that. But the question is how to sustain such an effort.

"We see no reason why, if we set up an efficient structure, it can't continue," says Friedman. But what kind of structure? Will it suffice to set a small advisory council to coordinate otherwise independent national efforts, as happened in the IGY? Or will it be necessary to set up a new international body? And not incidentally, who will manage the global data archive?

No one should have any illusion about how long this will take. The Global Atmospheric Research Project was first proposed by President John F. Kennedy in 1961; the first experiment was begun in 1978.

- Government support. IGBP has not yet gained much visibility in policy circles, so it is hard to say how enthusiastic the various national governments will be. On the positive side there is an honest scientific rationale to the program, there is a potential prestige value in participating, and there is the painful fact that in many countries, problems like acid rain and deforestation are of real practical concern.

On the other hand, there is the matter of money. The cost of IGBP is still nebulous, although the proponents have tried to be reassuring on at least one point: IGBP will *not* come on top of the existing international programs. Nor will it come at their expense. "IGBP will be a focus for their interaction," says Francis P. Bretherton of the National Center for Atmospheric Research, chairman of NASA's new Earth Systems Science Committee. "It will complement them."

- The U.S. program. "A U.S. national program doesn't make sense unless it's embedded in a global program," adds Bretherton. "The problems are so big, both conceptually and observationally, that the United States simply cannot do it alone.

"But to get a strong world program you need effective leadership," he adds, "and the United States is the *only* country able to take strong leadership. We have such a large fraction of the world's scientists that if this country can't get its act together, then the rest of the world can't."

Most scientists would probably agree with that statement. In essence, the Eddy committee is trying to formulate such a U.S. program. Congress seems receptive to having the United States take a lead. The science adviser's office at the White House likes the idea. But then, no one has asked for any money yet, either.

In the last analysis, of course, the question is really one of political will. "Scientists are more than willing to join forces," said Friedman in his keynote address at the ICSU meeting. "Governments must be persuaded that it is in their interests to support international cooperation."—**M. Mitchell Waldrop**

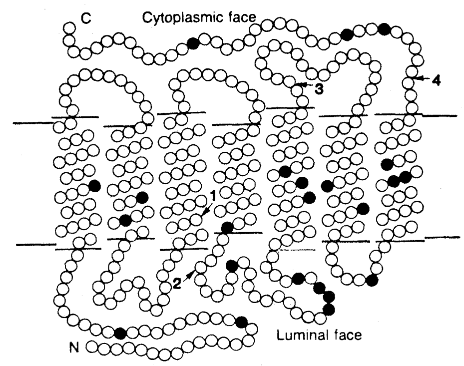
Pigment Gene Scrutinized

Jeremy Nathans and David Hogness, of Stanford University, have isolated and characterized the gene that codes for the protein component of human rhodopsin, the purple pigment that underlies high sensitivity, or night vision (*1*). Their analysis of the implied structure of the protein, opsin, gives interesting insights into its detailed conformational arrangement within the photoreceptor cells, which are known as rods. The Stanford researchers' interest in the rhodopsin gene is, however, only a stepping stone to a better understanding of the curious problem of color vision.

Abnormalities in color vision represent one of the most common and widely known genetic defects among human populations. Although it is usually assumed that the genetic aberration in color blindness affects the protein structure of the visual pigment located in one or more of the three classes of photoreceptors employed in color vision—red, green, and blue cones—this has not been unequivocally demonstrated. One very good reason for this is that no one has unequivocally demonstrated that the different absorption spectra of the cones are the result of differences in protein structure of the pigments.

Pigment profile

The rhodopsin molecule is folded and embedded in the disc membrane of the rod cell. Open circles represent amino acids in the human protein, with filled circles showing substitutions compared with bovine rhodopsin. Numbers 1 to 4 indicate intron positions.



Nathans and Hogness therefore plan to use the rhodopsin gene as a hook with which to go fishing for the putative three cone pigment genes. Analysis of the DNA sequence of these genes will give some indication of structural differences in the encoded proteins. In addition, they hope to synthesize enough of the proteins in vitro to be able to assemble the suite of cone pigments and thereby test the effect of differences in primary structure of the proteins on their light absorption properties.

Rhodopsin, like the cone pigments, is embedded within membranes, or discs, stacked within the photoreceptor cell. Drawing on a model for the disposition of a related protein, the much-studied bacteriorhodopsin within its membrane, Nathans and Hogness describe the folding of the 348-amino acid-long rhodopsin protein chain within the disc membrane. The protein passes through the membrane seven times, leaving the N-terminal region on the luminal face and the C-terminal on the cytoplasmic face. Comparing this arrangement with that for bovine rhodopsin, the gene for which the Stanford team had isolated as the initial phase of their program (*2*), shows that the three protein loops on the cytoplasmic face of the membrane are perfectly conserved. The reasonable inference is that these regions are important in initiating nerve impulse generation once the pigment has absorbed light.

Analysis of the human gene structure reveals that the coding sequences, exons, are interrupted by four noncoding regions, introns, a pattern that is repeated precisely in the bovine gene. Moreover, three of the introns (2, 3, and 4) interrupt the gene at the junction between membrane and extramembrane segments. The pattern, details of which are to be seen in membrane-anchoring segments of surface immunoglobulin and histocompatibility antigens, is nicely consistent with the idea that at least some genes are assembled from structural or functional domains.—**Roger Lewin**

References

1. J. Nathans and D. S. Hogness, *Proc. Natl. Acad. Sci. U.S.A.* **81**, 4851 (1984).
2. ———, *Cell* **34**, 807 (1983).