GLOBAL CHANGE: THE SCIENTIFIC CHALLENGE

Research in the next decade holds the key to understanding the environmental problems of the next century

Second in a two-part series

By RICHARD MONASTERSKY

A decade or more may pass before climate experts can say whether greenhouse gases building in the atmosphere have truly started warming the world's surface. But the scientific community isn't just sitting by the thermometer, waiting for the heat to happen.

"We believe that global environmental change may well be the most pressing international issue of the next century," asserted the presidents of the National Academy of Sciences, National Academy of Engineering and Institute of Medicine last December.

To meet the challenge, scientists are laying out the course for global change research, devising broad battle plans for the next decade and beyond. NASA has even coined the term "Earth system science" to describe a boundary-breaking discipline that examines all aspects of global change, even processes that occur over geologic time spans.

Researchers involved say the 1990s must bring major advances on many different fronts to fill some glaring gaps in their knowledge about Earth. In a recent report, the President's Committee of Earth Sciences outlined a triad of broad research objectives shared by other U.S. and international committees. Reaching far beyond the issue of greenhouse warming, these goals address all aspects of environmental change, including acid rain, ozone loss and even natural processes such as volcanic eruptions. The three scientific objectives are to establish:

- long-term monitoring programs to observe any global change.
- focused research campaigns to better understand global processes.
- better conceptual and computer models to predict future change.

Monitoring Earth's vital signs

Temperature records reaching back into the late 1880s show that the Earth's average annual temperature has warmed over the last century by at least 0.3° to 0.4°C. Carbon dioxide measurements since 1958 testify that the atmospheric concentration of this gas has risen from 315 parts per million by volume to more than 350 ppm. Yet scientists know next to nothing about the history of many other extremely important global characteristics.

"We really are changing our Earth in measurable ways, so we better damn well know what we are doing to it," says Ralph Kahn, a planetary and climate researcher at the Jet Propulsion Laboratory in Pasadena, Calif.

Scientists say they need to monitor scores of global characteristics, ranging from Earth's distribution of clouds to the amount of vegetation covering the continents and filling the surface layers of the oceans. Such information will not only pinpoint how the globe is changing, but also help scientists understand how the Earth works in general.

John A. Eddy, director of the Office for Interdisciplinary Studies in Boulder, Colo., calls global monitoring the most pressing task facing scientists concerned with the environment. "We know that this information, more than anything, is going to be badly wanted down the line," says Eddy, a former chairman of the National Academy of Sciences' Committee on Global Change.

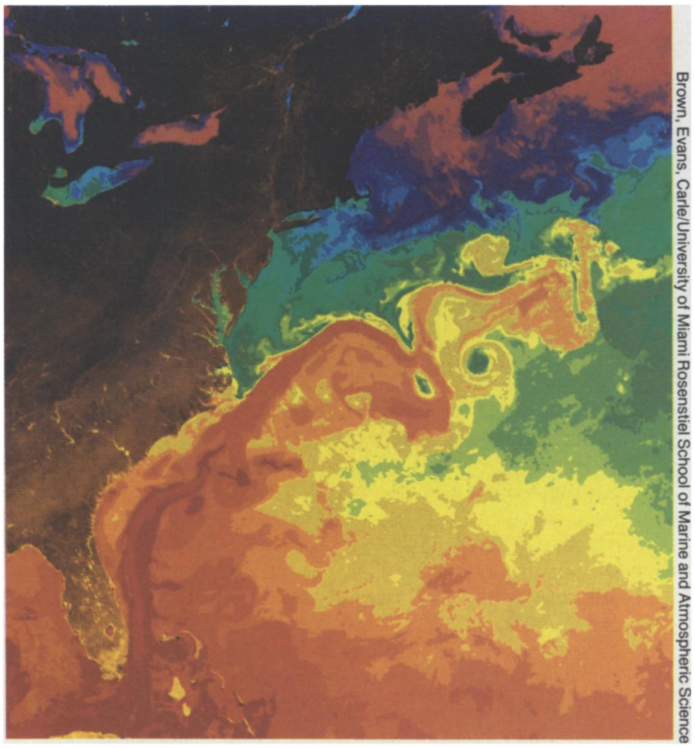
Programs are already underway to gather data on a small sample of Earth's vital signs, although many of these data come secondhand from sources having specific purposes other than long-term monitoring. For example, scientists studying how climate has changed over the last few decades use wind and temperature measurements taken routinely for weather forecasting by thousands of small weather stations.

Many problems plague these borrowed data. For instance, while rain and snow records go back more than a century in certain areas, scientists cannot use them to track global shifts in precipitation because the available records lack information for vast areas of the Earth, including all oceans. Researchers also question the existing data's quality.

In the next decade, scientists plan to initiate a true program of global monitoring — what NASA calls a "new era of integrated global observations of Earth."

While measurements from the ground, balloons and aircraft will continue to provide important information, satellites will take center stage in this new age of observations. These orbiting eyes have granted humans the ability to watch the entire globe, often with remarkable accuracy.

As a sample of coming achievements, scientists are refining techniques to measure the height of the sea surface with an accuracy of a few centimeters. For



A conveyor belt for heat: Warm waters of the Gulf Stream stand out in this image of sea-surface temperatures taken by infrared meters aboard the NOAA 7 satellite in early June 1984. Temperatures range from red, which denotes warmest water, through orange, yellow, green and then into colder blues and purples. Water temperature in the Gulf Stream off Miami is about 27° C. Satellite data over many years will help scientists detect long-term changes in global ocean temperatures.

Brown, Evans, Carle/University of Miami Rosenstiel School of Marine and Atmospheric Science this, they use satellite lasers that send light pulses racing more than 1,000 miles on a round trip to the Earth's surface and back into space. Since the slope of the ocean surface directly relates to its surface currents, this technique will help scientists study the huge streams of water that transport heat and nutrients around the world.

Satellite data and information gathered at the surface will also catalog the vegetation covering the globe. Scientists need such information to measure how quickly humans are razing forests, particularly in the Amazon – a process that contributes to the buildup of carbon dioxide in the atmosphere. Satellite sensors will track shifting sands that could consume land on the rims of deserts as the climate warms. Some instruments will even monitor changes in the sun's radiation, a poorly understood variable that could play an important part in Earth's long-term climate.

In the next few years, scientists will try to decide what global variables should receive top priority, and then choose the best methods for monitoring. In many cases, this will require developing new instruments.

Researchers look to the mid-1990s for the beginning of a new phase in satellite observations, ushered in by the proposed Earth Observing System (Eos), a group of at least four polar-orbiting satellites – two from the United States, one from Europe and one from Japan. These polar-orbiting craft will carry 30 instruments designed to record observations for at least 10 years. NASA, which coordinates the Eos program, plans to launch the first satellite around 1996.

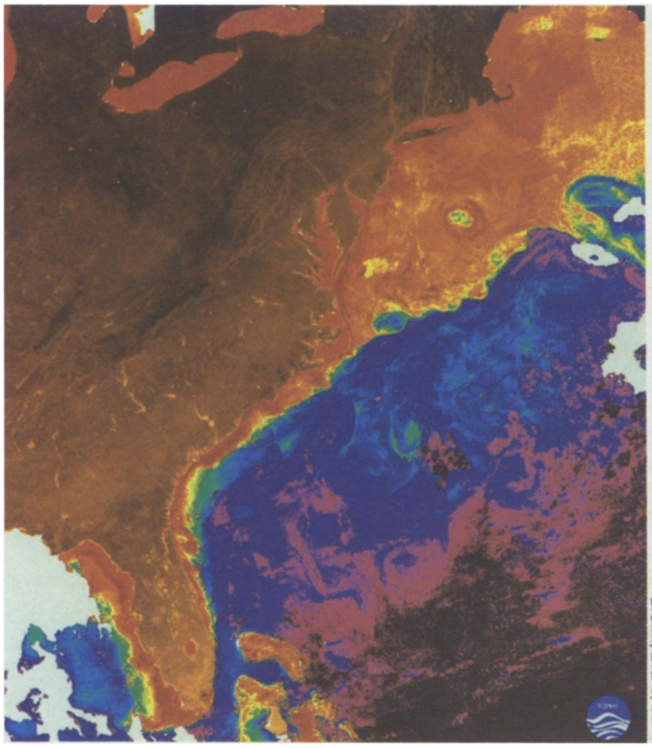
Eos planners want to build an unusual amount of flexibility into the program so that scientists can one day address questions they have not yet even considered. "There is no doubt that by the time this bird flies, the prevailing questions are not likely to be the questions of today," says Gerald A. Soffen from the NASA Goddard Space Flight Center in Greenbelt, Md., project scientist for Eos.

Eos will present scientists with some unprecedented problems. Perhaps the greatest involves handling the deluge of data coming from the satellite sensors. Jet Propulsion Laboratory's Kahn and NASA Goddard's Henning Leidecker reported in the winter RENEWABLE RESOURCES JOURNAL that Eos instruments will send to Earth 1 trillion bits of information per day. In less than a week, they say, the Eos data will outnumber all present geoscience information stored on magnetic tapes, in books and elsewhere.

Those preparing for Eos will have to develop systems to store these data, process them and make the information readily available to investigators.

Understanding the web

In 1985 and 1986, the first reports of a dramatic environmental problem – the Antarctic ozone hole – shocked atmospheric scientists. No one had anticipated that half the ozone could disappear from the skies above Antarctica for several months. No theory or computer model could decipher the phenomenon's cause. Yet within three years, scientists developed an explanation for the events in the Antarctic atmosphere. The solution came from a series of research campaigns that gave scientists the hard data to test new theories.



Spring in the North Atlantic: Tiny plants called phytoplankton bloom during May 1982 in surface waters above the continental shelf and slope. The northern edge of the Gulf Stream marks a border between areas of greatest phytoplankton concentration, shown in orange and red, and less productive areas denoted by blues and purples. This image features satellite data taken by the Coastal Zone Color Scanner, which measured ocean chlorophyll before it ceased operating in 1986.

Brown, Evans, Carle

Scientists say they will turn this sort of attention on many other important but poorly understood processes affecting the Earth. Such focused programs form the second leg of the global-change research triad.

One program, the World Ocean Circulation Experiment (WOCE), starts next year and should run through 1997. Researchers from the United States and at least 20 other countries will examine the ocean circulation patterns that affect, among other things, how the oceans store heat and absorb greenhouse gases from the atmosphere. Such matters play a crucial role in determining the speed of the greenhouse warming. WOCE will combine observations taken from satellites, ships, stationary moorings and drifting instruments.

Eric J. Lindstrom, director of the U.S. WOCE project office in College Station, Tex., says this experiment's two basic objectives fit directly into global change studies. One objective is to gather data and develop theories that help experts build realistic computer models. Researchers need these ocean models, which simulate the basic circulation, in order to forecast the role oceans will play in future climate change. A change in ocean circulation could drastically alter the rate of greenhouse warming.

The experiment's other objective lays the groundwork for a future system to observe ocean circulation. WOCE's new generation of instruments will assist in the monitoring effort long after the experiment has ended.

Most of the focused research projects scheduled for the next decade have similar goals. These programs will investigate nutrients in the ocean, worldwide precipitation and the chemistry of the atmosphere, as well as several other global features.

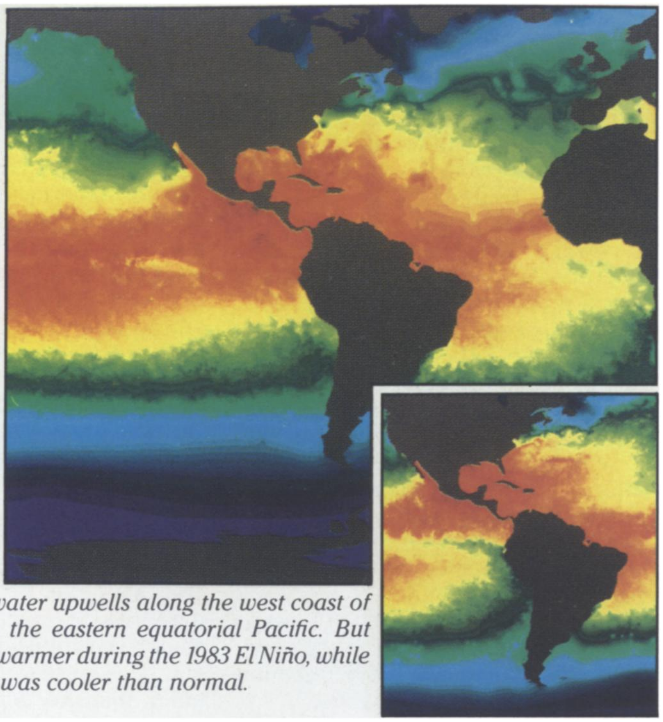
Experts say much work in the future must concentrate on how living organisms fit into the global climate equations. For instance, scientists will try to measure the total amount of carbon dioxide that plants pull from the atmosphere.

"Our knowledge is weakest quantitatively in everything to do with the biology, particularly the way biology works on a continental scale or bigger. That is one of our most profound areas of ignorance," says Francis P. Bretherton of the University of Michigan in Ann Arbor, who chaired NASA's Earth System Sciences Committee.

The human dimension of global change is another subject in need of study. According to the National Academy of Sciences, researchers seeking to develop likely scenarios for future changes must systematically document how humans have already altered vegetation and used natural resources.

Forecasts for the future

When NASA climatologist James



Hot times in the Pacific: While scientists expect greenhouse gases to warm the world's oceans, natural climate swings like El Niños also can drastically affect ocean temperature, making it difficult to distinguish the "fingerprint" of a human-induced warming. In this 1983 image, infrared information taken by satellite shows the warmest waters in red, while green and blue denote colder temperatures. In a more normal year like 1984 (inset), cold water upwells along the west coast of South America and in the eastern equatorial Pacific. But these areas were much warmer during the 1983 El Niño, while the equatorial Atlantic was cooler than normal.

Brown, Evan, Carle

Hansen announced last summer that the greenhouse effect lay behind the recent rise in global temperatures, debate quickly focused on whether the expected greenhouse warming had indeed started. But for climate experts, that question sidesteps the most important issues in this subject. Most believe greenhouse gases will raise the average temperature of the planet soon, if they haven't already. The real questions are the speed of the future warming and how the climate change will affect specific regions.

Such issues fall into the realm of computer models. Using large, complex programs that simulate Earth's climate, scientists are trying to forecast how the planet will react to the greenhouse gases.

For the most part, these climate models contain a collection of mathematical equations representing basic physical processes in the atmosphere. The most complex programs, called general circulation models (GCMs), attempt to simulate all three dimensions of space and can only be run on supercomputers. These models break Earth's atmosphere into several layers, sectioning the surface of each layer into thousands of rectangular grids. Because oceans strongly influence the climate, modelers include mathematical oceans in the atmospheric GCMs.

To get an idea of what the greenhouse effect will do to climate, modelers run the GCM models with an Earth that has significantly more carbon dioxide in the atmosphere, usually double or quadruple the concentration in 1958.

The concept sounds simple, but the process isn't. To complete the simulation, the fastest supercomputers, which are very expensive to operate, require hundreds to thousands of hours, says Michael Schlesinger, a climate modeler at Oregon State University, in Corvallis. Around the world, only five institutions, including Schlesinger's, have run the simulations to completion.

Those five GCMs project that Earth's average surface temperature will warm by 1.5° to 5.5°C by the middle of the next century, the time when scientists expect carbon dioxide and other greenhouse gases to reach at least double their preindustrial levels.

Aside from global temperature predictions, the double carbon dioxide runs offer scientists a view of more specific effects. For example, they predict polar regions will warm more than the tropics, and the interiors of North America and Asia will dry out while other areas, such as Bangladesh, will face stronger monsoons.

Can these future forecasts be trusted? Climate experts answer with a resounding "yes and no."

Model builders have tested their creations in a couple of ways. One method tries simulating the seasonal variations in weather. In another, modelers attempt to recreate the climates of ancient periods in Earth's history.

The programs simulate some conditions, such as seasonal changes, quite well. But many models have problems duplicating the climate conditions geologists believe existed during the Cretaceous period, more than 65 million years ago, when Earth was much warmer than today.

Modelers have clear ideas of where their creations are currently lacking. In general, scientists know far less about the oceans than they do about the atmosphere. So oceans form the weakest link in the GCMs.

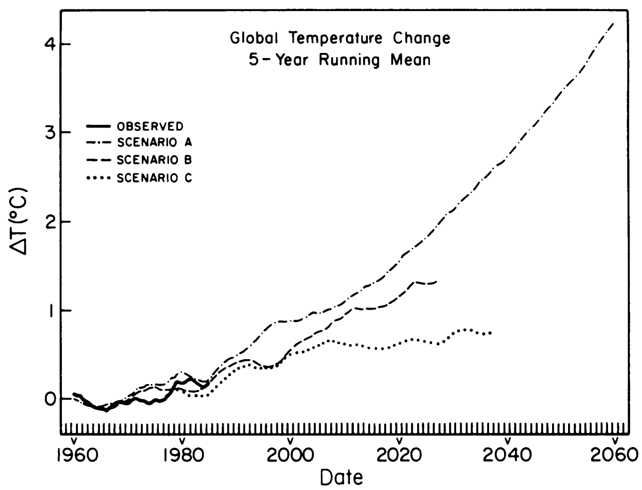
In the double carbon dioxide runs, modelers have not even used their best ocean models. All these calculations have included extremely simplified oceans that lack currents and other essential characteristics.

More realistic ocean models exist. But, like the oceans, these mathematical bodies of water are sluggish beasts, taking 1,000 years or more to react fully to a doubling of carbon dioxide. Including such oceans would multiply the required computer hours 50 times, so no one has run a double carbon dioxide simulation to completion with a coupled atmosphere-ocean GCM, Schlesinger says.

Clouds create another big problem area in climate models, says Warren M. Washington, director of the Climate and Global Dynamics Division at the National Center for Atmospheric Research.

Limitations in computing power have forced modelers to fudge the way they deal with clouds. Individual clouds are much smaller than the grid sizes of the atmosphere in current GCMs. Researchers, therefore, have introduced a general "cloudiness" factor into their programs, but this may not successfully simulate how alterations in clouds affect

Warm choices for the future? Results from one climate model predict how quickly Earth's surface will heat according to three scenarios. Case A assumes greenhouse gases will continue to accumulate at an exponential rate. B assumes a slower, steady rate of growth. C assumes a rapid end to the rise.



Hansen et al./Goddard Institute for Space Sciences

U.S. global change research: Who's in charge here?

U.S. research on global change shares something in common with the legendary horseman who roamed the hills of Washington Irving's Sleepy Hollow: They both appear to lack heads.

A number of federal organizations conduct or sponsor work relating to environmental change, including NASA, the National Science Foundation, the National Oceanic and Atmospheric Administration, the Environmental Protection Agency and the Department of Energy. Yet no one agency has the official charge, or a large enough slice of the research pie, to coordinate this entire field of diverse government projects. In the minds of some scientists, this has hurt the effort.

"There definitely is a need for some sort of guidance," says Gordon J. MacDonald, chief scientist at the MITRE Corp. in McLean, Va., who recently directed a group of experts pinpointing weaknesses in current climate research (SN: 3/11/89, p.150). "The problem is very real. We could go another 10 years and not be in any better shape than we are now to look to future issues."

In the past year, the White House's Committee on Earth Sciences (CES) has partially filled this gap in organization. In a report issued in February, the CES introduced initial strategies for a U.S. Global Change Research Program. Working closely with the Office of Management and Budget, CES proposed increasing funding in global change studies from $134 million in fiscal year 1989 to $190 million in 1990. Now the group is devising a research plan that examines in detail the programs in each agency.

MacDonald, however, criticizes CES' effectiveness. "It hasn't attempted to look through the programs and determine what is missing," he says. "It certainly did not provide any guidance on setting priorities."

But D. James Baker, president of the Joint Oceanographic Institutions Inc. in Washington, D.C., says the CES has accomplished some impressive work so far. "Their report is really a first for cross-cutting agency activity," says Baker, who sat on MacDonald's oversight group.

Whatever their thoughts on the CES, many researchers say the real problem stems more from lack of money than from lack of organization. "Right now we are at a crucial stage. We can no longer generate more plans; we have to generate action," says Harold Mooney of Stanford University, who heads the National Academy of Sciences' Committee on Global Change. This is the U.S. affiliate of the International Geosphere-Biosphere Program, a group trying to coordinate worldwide work on the biological aspects of global change.

Some scientists point to the National Oceanic and Atmospheric Administration (NOAA) as a glaring example of the problem in funding and priorities. An advising panel to NOAA reported in January that the organization has not fulfilled its original charter of developing a "better understanding of the total environment." Buried within the Department of Commerce, NOAA has received insufficient support to assume its designated role as leader of global monitoring efforts, says John A. Eddy, chairman of the advising panel. "The bottom line," he says "is that the global change program needs NOAA badly."

– R. Monastersky

global warming.

The cloud problem could be quite significant. Atmospheric scientists regard clouds as the wild card in the deck of changes that will accompany global warming. These puffs of ice and water particles might amplify the warming or they might slow it down. Modelers in the next decade will attempt to test for such feedback effects.

Solutions to the current modeling problems depend heavily on information from real-world experiments, such as WOCE. Without this, modelers cannot know what processes they need to recreate. Increases in computer power from a new generation of supercomputers also will help, as will building parallel processing into the models. These advances should help scientists run more realistic models, perform more experiments with existing programs and develop forecasts for specific parts of the globe.

While GCMs are the most complex programs in the geosciences, they essentially include only physics; their biological and chemical processes are primitive at best. Berrien Moore III, director of the Institute for the Study of the Earth at the University of New Hampshire in Durham, quips that GCMs represent all of terrestrial life with the mathematical equivalent of green sponges. As opposed to the incredible complexity of living systems, the mathematical life in GCMs essentially does no more than absorb or release water.

Eventually, researchers want to build comprehensive climate models that include significant amounts of biology and chemistry, says Jorge L. Sarmiento, director of the Program in Atmospheric and Oceanic Science at Princeton (N.J.) University. Land plants, tiny ocean organisms and a host of other features might spawn feedback effects that slow or speed global change. Without comprehensive models, scientists will be unable to identify these feedback effects, says Sarmiento, who is currently working on a model of the Atlantic Ocean that couples ecology with ocean circulation.

The combined effort

Though they fit neatly under separate headings, the three broad paths of global change research will not run isolated courses. The modeling effort will draw heavily on data and theories garnered from focused research projects and monitoring programs. In return, experiments on computer models will illuminate areas for future monitoring.

The need to understand and predict global change is forcing scientists to redefine the way they look at the world. In the past, science has carved the Earth into separate chunks. To geologists went the planet's crust. To biologists went the living kingdom. Oceanographers got the great basins of water. Yet environmental change cuts across traditional academic borders. Scientists dealing with the Earth as a whole will have to broaden their vision and collaborate more than they have in the past.

While encouraged by the growing public concern for global change, researchers worry about possible political problems that might emerge. Says Bretherton, "Policy issues are going to put a lot of pressure on scientists to come up with answers. In fact, the scientific community will not be entirely at liberty to set its own agenda."

Such issues will be new to the geoscience community, which has not routinely faced the race-against-time pressure that medical researchers often encounter.

Scientists say politicians need to understand that answers will not come instantaneously and that research must continue for decades. At the same time, some researchers worry that in a few years, policymakers might decide they know enough and withdraw support for global change research. "I think that is very, very dangerous," says Moore.

Those fashioning research plans for the future also fret about more subtle problems that could plague their planning efforts.

In some matters concerning the Earth, Bretherton says, the scientific community is so ignorant that it probably cannot map the best course toward knowledge. "There is a real tension here. We realize that we don't understand enough about this problem to really define what we need to do, and yet we need to get on with a focused program that will actually make some progress. As such, we tend to concentrate on those things that we think are do-able." Those plans are certainly ambitious, but Bretherton wonders whether they will be radical enough to serve the needs of the future world. □