# Keeping Watch on the Earth:
# an Integrated Global Observing Strategy

by

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Unlike the terrestrial globes that stand in our libraries and offices, the Earth itself is ever changing, as is evident in clouds and storms and the passage of the seasons. The levels of lakes and oceans rise and fall, as does the land itself. Glaciers come and glaciers go. Even the continents move.

Human beings have watched these and other changes in the natural world since the dawn of civilization, and for several thousand years have endeavored to document and measure them. But ours is the first generation with the ability to see and quantify these patterns of change on a global scale. We can view the entire surface of the Earth from the vantage point of space, and we now share this information, freely and instantly, around the world.

These new abilities come at a time of tremendous economic and social expansion, and have become indispensable because of these changes. The population of the world has grown from just over two billion people in 1930 to almost six billion today and will likely reach twelve billion sometime in the next century. World economic output has grown even faster than population itself, rising from $13,500 billion in 1970 to $31,000 billion per year in 1994.

The effects of increasing population and rising consumption have reached the point where we now affect the global environment including the chemistry of the air and, to a degree yet unknown, the climate of the entire planet. For better or worse, we stand on the brink of two unprecedented developments in human history: (1) the ability to alter the natural environment on a global scale, and (2) the capacity to detect and track the course of these changes and thus understand and respond to them. The former can happen without much forethought. The latter cannot.

This article examines the part of this challenge that depends on systematic observations of the Earth, and points to the advantages of pursuing an integrated global observing strategy dedicated to this task.

## AN HISTORICAL PERSPECTIVE

In the U. S., public recognition of the environmental impacts of human activities is more than 100 years old, stemming from the efforts of such colorful and diverse personalities as John Wesley Powell and Theodore Roosevelt. In the 1960s, however, a broader public awareness emerged with the advent of the Space Age. Our first-ever look at the entire planet--a color photograph taken in 1968 from Apollo 8 on the first manned flight to the Moon--gave us as well our first chance to see the Earth from afar: round and blue in the black immensity of space. This single image so seized the public imagination and so concentrated a developing international concern that the world's first Earth Day was celebrated but two years later.

The new look at ourselves from space, so unlike the static globes of old-time geographers, conveyed a sense of action, change, and inter-connection. Later images from space showed mighty dust storms sweeping across the Sahara, initiating a process of atmospheric transport that would fertilize the Amazonian rain forest, 6000 miles away. The view from space also identified the largest polluted air mass in the world--not over Los Angeles, or Moscow, or Mexico City, but above the uninhabited South Atlantic--and it allowed us to identify its many small sources, where fields and trees were deliberately being burned in Africa and South America. The global view from space, in 1964, offered the first cinematographic images of clouds from a satellite in a *geostationary orbit:* far enough away to circle the Earth in synchrony with the planet's rotational period of 24 hours, thus allowing an uninterrupted view of a selected area, such as the Western or Eastern U.S. These pictures, now a common staple of televised weather broadcasts, communicate the awesome power of weather systems and a sense of how their paths are projected forward in practical weather prediction.

Meteorology was the first scientific discipline to utilize continuous, or real-time observations to predict changes in the environment. Telegraphic exchange of barometric pressure data, initiated by the French astronomer LeVerrier in 1876, enabled one-day weather forecasts over Europe. Beginning **in the 1930s,** measurements of the air above the surface were routinely made from instrumented balloons, or *radiosondes,* and by the 1950s extensive compilation of these data made one- to two-day regional forecasts possible. By the 1970s global numerical weather predictions had been pushed another day in advance, thanks to a network of surface and upper-air observations organized by the international World Weather Watch. Finally, in the 1980s, extensive use of computer models of the atmospheric circulation that were driven by observations from polar-orbiting and geostationary satellites enabled forecasts to be extended to five days. The lesson was clear: accurate weather prediction beyond a couple of days requires global coverage.

## ENVIRONMENTAL PROBLEMS THAT DEMAND GLOBAL DATA

Is there hope of extending the range of reliable weather forecasts any further? The answer is yes, but the challenge requires monitoring a broader set of variables and help from scientific disciplines that lie outside the traditional domain of meteorology. The first of these areas of study are oceanography (because of the exchange of energy and fresh water between the oceans and the atmosphere), geography (through the effects of surface features on air circulation), and atmospheric chemistry (because of the impacts of trace chemicals and solid particles on atmospheric radiation). A newer tier includes hydrology, soil science, and plant ecology. Each of these disciplines, like meteorology, now utilizes global Earth observations from space. Through the early initiatives of NASA and of other national and international research efforts--including the multi-agency U.S. Global Change Research Program (USGCRP)--scientists from these and other fields now work together to provide a more multidisciplinary approach to environmental questions.

The current definition of the USGCRP identifies four major challenges in global environmental sciences. Two of them deal directly with climate and all of them address not only important scientific frontiers, but areas of research that are directed at practical applications and societal benefits. These four priority areas of research are:

- Stratospheric ozone depletion and increase in surface WV radiation;
- Prediction of seasonal-to-interannual climate fluctuations;
- Climate change over decades and centuries; and
- Changes in land cover and in terrestrial and marine ecosystems.

In the order given here, they run from most mature to more exploratory in terms of our ability to acquire the relevant observations, to understand the mechanisms involved in the observed phenomena, and to inform social and economic decision-makers of their impacts.

## A PATHFINDER FOR INTERNATIONAL SCIENTIFIC DECISION MAKING: STRATOSPHERIC OZONE AND UV RADIATION

Environmental consequences of industrialization have long been viewed in terms of their local or in some cases, regional impacts. Changes in air or water quality and ground pollution were customarily recognized at the level of cities or regions, as were remedial actions, *even* if controls were mandated through national legislation. The discovery of an annual springtime depletion of stratospheric ozone *over* Antarctica, about ten years ago, provided evidence, for perhaps the first time, of an environmental impact of a much broader, global scale that was directly traceable to a single human activity. As a result of this discovery, new ground was broken in linking scientific findings and international policy action.

Between 1970 and 1974, scientists in the U.S. and other countries had raised the possibility that manmade compounds of chlorine, fluorine, carbon, and hydrogen *(chlorofluorocarbons,* or *CFCs)* could *bring* about a global depletion of ozone in the stratosphere. CFCS do not arise from natural processes, but are produced commercially as relatively inert gases for home refrigerators and automobile air conditioners, the production of foam plastics, and gas-propelled sprays. Released at ground level, these long-lived gases would according to theory rise by convection tens of miles into the air, where through a mixture of sunlight and chemical processes they could eat away at the Earths protective ozone layer. After an initial flurry of public interest, the policy debate subsided, primarily because of the lack of observational evidence for the predicted effect.

Ground-based measurements suggesting significant global ozone depletion and the appearance of a springtime Antarctic “ozone hole” were first reported a decade later, in 1985. While the effect was first detected in measurements made from the ground, identifying the cause of diminished ozone required *in situ* observations--by means of instruments carried in jet-aircraft to stratospheric altitudes where the chemical reactions were taking place. But measurements from aircraft could not determine the global extent of the phenomenon. Variations in the size of the annual “ozone hole” from 1979 on were reconstructed from measurements taken from space by NASA's polar-orbiting Total Ozone Mapping Spectrometer. More comprehensive evidence that Antarctic ozone loss is of human origin was provided by the agency’s Upper Atmosphere Research Satellite that was launched in 1991.

No one nation is uniquely responsible for the destruction of ozone in the stratosphere, nor can any country, acting alone, put the brakes on this unintended but potentially serious interference with one of the planet’s natural safeguards. At the time, CFCS were produced *or* employed in manufacturing in many industrialized nations, and released in some form in every country. The probable consequences appear to be as widespread as the causes. Reduction in total ozone in the atmosphere allows a heavier dose of solar ultraviolet radiation to reach the Earth’s surface, with potentially serious effects on skin and eyes and the immune systems of people everywhere. In view of this hazard, and as soon as the main cause for ozone loss became reasonably clear, 148 of the world’s nations signed the 1987 Montreal Protocol on Substances Depleting the Ozone Layer and ensuing amendments that bamed the production of CFCs.

It was the second time in the history of the world that nations acted together, by treaty, to limit the harmful impacts of a particular activity on human health and the global environment. Like the Nuclear Test Ban Treaty of 1968, the Montreal Protocol provides a beacon of hope for future international action on environment protection.

Today, ground- and space-based sensors are used to verify that the Montreal Protocol is in fact working. Declining concentrations of key ozone-depleting substances have been found by a network of surface stations and satellite measurements. Yet there is still no firm international agreement to monitor ozone from space, nor any commitment to maintain the appropriate ground-based networks for ozone and ultraviolet radiation measurements. As a result, the door is still open for possible future surprises insofar as ozone and UV radiation are concerned.

## THE PRESENT CHALLENGE SEASONAL TO INTERANNUAL CLIMATE PREDICTION

Throughout most of the first half of the present century, weather predictions were made for one or at most two days in advance. Yet, as noted earlier, in a span of forty years the useful range of such predictions was extended to five days--a working week--with important gains for human decision-making. Still, many of our endeavors, including most notably agriculture, operate on time scales of a season or a year or more. Can we learn to predict regional variations in weather patterns and climate several months, or a year, in advance? As we shall see, this cannot be done without more comprehensive observations--particularly measurements of winds over the surface of the oceans, the heat content of the upper ocean, precipitation over land, and the storage of moisture in soils.

In short, the challenge of seasonal-to-interannual (S1) climate prediction calls for an observational strategy of more dimensions than what is needed for day-to-day weather forecasts or for tracking stratospheric ozone. A wider range of variables must be monitored, some by sensors on ocean platforms, some on the land, and others on spacecraft in equatorial, inclined, and polar orbits. Moreover, because climatic changes on time scales of months and seasons are part of large scale, global phenomena, a variety of regional impacts are possible, including the simultaneous occurrence of floods at one location and drought at another. Thus, no single mitigation strategy is possible for all regions, as was the case for ozone depletion.

The study of SI climate variability touches upon social as well as natural science issues. How reliable need long-term forecasts be, and how far in advance need they be made to be useful? What are the implications, for agricultural or insurance and investment decisions, of both successes and failures? These challenging and very practical questions define S1 forecasting as a powerful test **case** in framing what we shall call an *integrated* global observing strategy.

## How ready are we?

A recent study by the U.S. National Academy of Sciences (NAS) cited S1 climate prediction as a maturing field with high relevance to economic and other practical decisions. The NAS noted that scientists have now identified the fundamental science questions: Where does significant S1 variability exist, and what are its patterns? What mechanisms underlie this variability and how do they evolve across space and time? What are the effects of SI variability on natural systems and human interests? How predictable are S1 variations and their effects?

The NAS also noted that considerable progress has already been made. The largest contributor to global climate variability on S1 time scales is the transfer of heat and other forms of energy between the atmosphere and the ocean. These exchanges operate on time scales of seasons to years, and are initially manifest as distinctive surface warmings of the tropical Pacific Ocean, known as *El Niño* events, and associated changes in the global atmospheric circulation called the *Southern Oscillation* phenomena. Organized field studies of El Niño and Southern Oscillation (ENSO) phenomena over the last ten years have identified causes and effects, and scientists are now beginning to model and predict these climate anomalies with some success up to one year in advance. A practical prediction system that links observations and models in regions affected by El Niño--

particularly the nations around the Pacific Ocean--has been designed and partially implemented.

In middle and high latitudes, considerable investments have been made in the American Midwest, the northern slope of Alaska, and many other locations worldwide to deploy measuring networks for systematic observation of the chemical composition of air, cloud cover, and radiation, all of which are critical elements of seasonal climate change. Soil and vegetation processes are also very much involved in the exchange of energy, water, and carbon between the land and the atmosphere. Thus, regional information on soil moisture and plant conditions is another requirement of models that can project climate months or years in advance.

The need for multidisciplinary observations and analysis is well recognized by climatologists and the agencies that fund research. For purposes of weather and climate prediction, dedicated spacecraft are now making or will make observations that go far beyond the conventional meteorological suite of air temperature, pressure, moisture, and cloud-cover data. These include the temperature of the surface of the sea and the winds that blow across it; sea-surface topography and roughness; ocean circulation; and global precipitation including all that falls, unseen, on the oceans. To support internationally-organized research programs such as the study of the Tropical Ocean and Global Atmosphere (TOGA), the Global Ocean-Atmosphere-Land System (GOALS) study, and the Global Energy and Water Cycle Experiment (GEWEX), multinational arrays of moored and drifting ocean buoys now provide continuous measurements of surface and sub-surface ocean conditions, and systematic observations are made of ocean temperature as a function of depth using expendable sondes that are dropped from cooperating vessels along commercial shipping lanes. In parallel, a number of interactive ocean-atmosphere-land models are being developed around the world.

In view of these advances, the NAS recommended that the next step toward practical seasonal to interannual climate prediction should be a project to_ the occurrence and regional impacts of future ENSO events, as a way of demonstrating the benefits and practical limitations of S1 predictions. To do this, researchers will attempt to provide both broad predictions of global scale phenomena and specific advisories regarding probable impacts and possible adaptation strategies in regions such as tropical South America or the western U.S. To realize the full value of predictions the project will need to become directly involved in local agriculture by recommending appropriate planting strategies, and in other sectors by advising on natural hazard preparation and mitigation. Needless to say, such a project reaches well beyond conventional scientific research and requires the active participation of relevant national agencies and of local and regional decision-makers.

**An international Institute for ENSO predictions**

A major step forward in predicting and responding to ENSO events was the recent formation of the International Research Institute for Climate Prediction (IRI), endorsed by sixteen nations of the Americas, the South Pacific, and the Pacific Rim of Asia. The IRI will coordinate (1) modeling and observing systems, (2) impact assessments; and (3) national responses to seasonal and interannual climate change. The new entity is unique in linking together the efforts of nations in different parts of the world, in bridging the gap between the natural and social sciences, and in bringing scientists and decision-makers together. If the IRI proves successful, the oceanic observation networks installed for the pilot **phase of the project could** be transformed into an international operational facility for observation and global prediction.

The challenge facing the IRI is to demonstrate a capability to collect and analyze data for the evaluation of expected impacts on regional scales. Reliable predictions of ENSO events and other transient variations, seasons to a year in advance, are of unquestionable economic and societal value, and will provide strong incentives for nations to support the implementation of a shared, international system to produce them on a regular basis.

## THE NEXT CHALLENGE: LONG-TERM CLIMATE CHANGES

Seasonal-to-Interannual climate prediction adds a new suite of ocean observations to the on-going data requirements for today's shorter, five-day weather forecasts. The next step--climate prediction covering a decade or longer--presents an even more difficult challenge because it requires a still wider range of observations and adds an obviously longer time-span to the necessary commitments of *resources* and efforts. At the same time the benefits, while the science is being developed, are more diffuse and uncertain. Yet the challenge posed by long-term climate change in terms of impacts on the global economy and the human condition invokes much bigger stakes: the Earth is the only known habitable planet and our overwhelming interest is to keep it so.

Understanding climate change on times scales of decades requires a correspondingly long commitment to consistent and well-calibrated data records. Early plans for NASA's Earth Observing System (EOS) were based on the view of the scientific community that a minimum of fifteen years of continuous monitoring would be needed to identify meaningful climate trends and to separate human effects from changes of natural origin. In fact, some of the key parameters that control the Earth's climate will need to be monitored for an indefinite period, in the same way that population is counted or economic indicators are monitored, year after year, today.

The data to be collected by EOS for the goal of projecting long-term climate change include measurements of *every* major component of the Earth system: global cloud cover; the amount of dust and other solid particles (or aerosols) in the atmosphere;

the radiation received from the Sun and that emitted by the atmosphere and the surface of the Earth; the temperature of the sea surface and the circulation of the oceans; changes in sea-level, around the world; the extent and thickness of ice sheets and glaciers; the amount and thickness of floating sea-ice; the chemical composition of the lower and upper atmosphere, including the fraction of "greenhouse" gases; and significant changes in vegetation and other measures of land cover. Finally, these data must be assimilated into computer-generated representations, or *models,* of global climate. Modelers must identify and weigh a wide variety of processes that generate or regulate climate variations across all time scales.

## The challenges involved

Designing an observing system suitable for long-term climate change studies is a daunting task, from both scientific and technical perspectives. Greater yet may be the challenge of securing and maintaining financial, policy, and organizational commitments to this task when governments expect relatively fast and identifiable returns from their investment in research. How can a costly scientific undertaking sustain the financial support of governments and popular interest, when it addresses time scales of decades to a century? How can it expect the support of taxpayers and the private sector when its findings could lead to recommendations that mandate potentially costly and possibly controversial changes in human behavior?

A partial answer to these vexing problems can be found in explaining global climate change projections in terms of impacts at the regional level. A 2° C rise in global mean temperature over 100 years (as estimated in the most recent, mid-range projections of the Intergovernmental Panel on Climate Change), is not likely to rank high among the concerns of the average citizen in this or any country. That such a change will result in a world-wide rise of half a meter in mean sea-level may pique, somewhat, the interest of the average person. When translated into regional and local consequences--such as loss of beaches and hazards to shoreline assets, impacts on agriculture, reduced availability of fresh water from wells, an increase in disease vectors, and attendant impacts on quality of life--long term climate forecasts become more broadly meaningful. If projections are sufficiently specific and reliable, impact assessments are possible for use in long term capital investment decisions and insurance planning.

The fact remains that scientists are as yet unable to specify, in more than general terms, the local impacts of long-term climate predictions. Moreover, the obstacles to this long-sought goal are not so much the spatial resolution of today's numerical models (now typically a square, several hundred miles on a side) or the limitations of computing equipment, but what we don't know about some of the basic physical, chemical, and biological processes that need to be taken into account. It is these basic unknowns that introduce the principal uncertainties in model results. Reducing them, one by one, is a priority objective of modern climate change research.

Most people, not surprisingly, have only limited understanding of either the strengths or the uncertainties of models on which climate projections are based. This may be one reason why so many remain unconvinced of the likelihood of global greenhouse warming. The best way to increase public confidence and build support for a long-term climate observing system is to demonstrate consistently successful, verifiable forecasts of shorter-term, seasonal-to-interannual climate changes. In the process, scientists will gain confidence in their ability to discriminate between competing causes of climate change, and skill in collecting and utilizing the vast amount of data required. Decision-makers will gain a better appreciation of the capabilities and limitations of longer-term climate predictions, as well as their demonstrated practical value.

## THE FUTURE CHALLENGE: ECOSYSTEM RESEARCH

Only the bare beginnings have been made to develop an observational strategy for assessing significant global changes in the behavior of living things and ecosystems. To date, most attention has focused on measuring and modeling global sources and sinks of carbon dioxide. This is in part because of the fundamental importance of carbon dioxide as a primary cause of global warming. It is also because the composition of the atmosphere is relatively easy to monitor, compared to other possible indicators of ecosystem change.

The biological world is intrinsically complex at almost any spatial scale, and our customary ecological indicators, such as plant productivity or microbial activity are most often highly site-specific: what happens in a patch of corn may have little relevance to an adjoining forest, swamp, or pond. Moreover, what applies in a meter-size plot within any of these sites may not describe the particulars in an adjacent sample of similar size. Thus, the act of averaging or generalizing--so necessary in coupled models that combine data from disparate sources--presents a particularly difficult challenge in the field of ecology. The *aggregation* of plot-scale observations into meaningful regional and global geographic information is a major scientific and data management challenge, as is the opposite step, the *disaggregation* of large-scale estimates of predicted changes, such as area-averaged rainfall, into realistic values pertinent to smaller scales.

The effects of human activities on natural ecosystems present both challenges and opportunities for the construction of land and marine observing systems. Human impacts on the natural world are often the source of controversy. The act of assessing information regarding these impacts--such as those that follow the clear-cutting of forests or the draining of wetlands--can pit the immediate users of natural resources against those people or institutions that are more concerned with the long-term health of the natural environment. Likewise, nations may be leery about the wide availability of detailed images of their own territory from space, for various political, military and economic reasons.

The very utility and commercial value of remotely-sensed land and marine observations can also complicate the development of an international strategy for observing natural ecosystems. At the same time, our limited experiences with visual images made from space suggest that a marketable product can also create opportunities.

Commercial firms are important consumers of data from the U.S.-built Landsat and the French SPOT Earth-imaging satellites, and a "value-added" data processing industry has now arisen to tailor the raw images from spacecraft to suit the unique needs of many different applications. The increasing demand for remotely-sensed images of various features of the Earths surface comes at a time when the costs of spacecraft and instruments are declining, such that private ventures are now being proposed to provide high-resolution satellite imaging systems and services on a commercial basis. Field observations of terrestrial ecosystems lack the commensurate commercial value that would elicit similar interest from the private sector, and programs to provide these data have developed on a more piecemeal basis through governmental sponsorship.

## AN INTEGRATED GLOBAL OBSERVING STRATEGY

Within the U. S., federally-supported research activities that bear upon the science of the environment are coordinated by the interagency U.S. Global Change Research Program, linking the efforts of twelve agencies and institutions. Similar initiatives have come into being in almost all other developed nations. The European Union is endeavoring to coordinate the environmental research activities of its twelve member states: Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, and the United Kingdom, combining the scientific and economic abilities of some 350 million people. International, cooperative research institutes have been or are being established in the Americas, Asia and Africa. The World Climate Research Program and the International Geosphere Biosphere Program are internationally-coordinated initiatives to address the fundamental science of major environmental problems, including, but not limited to, global climate change. The Intergovernmental Panel on Climate Change, sponsored jointly by the World Meteorological Organization and the United Nations Environment Programme (UNEP) conducts international assessments of scientific knowledge on future climate changes and their probable impacts and possible policy options to respond to them.

These internationally organized research activities all speak to the facts that (1) the major environmental problems of today transcend national boundaries, and (2) the study of global Earth system phenomena and processes require international collaboration- These statements also apply to the observational systems that are necessary to monitor significant changes and to supply the diverse data needed to understand them.

## Elements now in place or underway

The World Weather Watch, sponsored by the World Meteorological Organization, is the most mature international cooperative effort of this kind, but it is limited to meteorology. Other existing mechanisms that reach beyond the domain of weather include the Committee on Earth Observation Satellites (CEOS) established by the Group of Seven (G-7) major industrial democracies (Canada, France, Germany, Italy, Japan, United Kingdom, and U.S.), and three international observing *system* initiatives sponsored by several UN organizations and the non-governmental International Council of Scientific Unions. These three proposed systems are directed, respectively, at global climate (through the establishment of a dedicated Global Climate Observing System, GCOS), the global oceans (GOOS), and global terrestrial systems (GTOS).

These are all first steps, however, and several important elements are still lacking. One is adequate integration of space-based and *in situ* observations in the three domains, for there is no internationally-agreed-upon mechanism to rank relative priorities among them. A second missing link is a forum or other review process through which national agencies can coordinate their own activities to meet global needs: to ensure that observational programs--in space or from the ground--will provide uniform and continuous data for agreed-upon science priorities. In this sense, the present status of global observing systems is not unlike the case of stratospheric ozone, cited earlier: an international agreement to control substances that deplete ozone without an international strategy to monitor the effect of the treaty.

Many of the elements of an integrated Global Observing Strategy exist today in terms of on-going but separate observing programs and new initiatives. Combined world expenditures *on* non-military, space-based research observations of the environment will total approximately $15 billion for the decade of the 1990s, and twice that amount if one includes operational monitoring systems, such as the World Weather Watch. Much of the research investment will go into the International Earth Observing System (IEOS)--the first multi-national satellite array that is designed to address the multi-disciplinary nature of most environmental questions.

The IEOS will combine six major satellite programs conducted by the U. S., Japan, and European nations. Included are the U.S. Earth Observing System (EOS) and Polar Operational Environmental Satellite program; Japan's Advanced Earth Observing System (ADEOS I & II); the joint Japan / U.S. Tropical Rainfall Measuring Mission (TRMM); a joint French / U.S. mission that measures ocean height and surface characteristics (TOPEX-Poseidon); and the European Space Agency's ENVISAT mission. Still, the combination of systems and satellites is only loosely coordinated and there are no binding agreements to ensure that the flow of data from any of them will not be interrupted. The first series of spacecraft in the IEOS arrays will be launched within a five-year period beginning this year, in 1997. The spacefaring nations have not yet coordinated their plans for continuation beyond 2002, although given the long lead times involved in planning and implementing space missions, it is time to do so.

## The need for an underlying strategy

International discussions have already been initiated to define an Integrated Global Observing Strategy, or IGOS: the foundation and raison d'être for activities such as the International Earth Observing System effort. The initial impetus for this development came in a 1994 report of Japan's Space Activities Commission, which called for an international Global Earth Observation System to be deployed early in the new century. The Japanese suggestion kindled a U.S. effort that resulted in a white paper from the President's Office of Science and Technology Policy, proposing guidelines for international discussion and interagency consultations within the US. on the subject. European organizations such as the European Space Agency, the European Meteorological Satellite Commission, and the European Union have shown a growing interest.

An Integrated Global Observing Strategy is the first requisite for a global Earth observing system: an agreed-upon definition of what needs to be monitored, and why, how, and in what order. The first word, "Integrated", carries several intended meanings, One is the essential international character of the enterprise: the need to tie together the efforts and research investments of many nations, with the broadest possible participation. The obvious need to share costs is but one of the reasons to make such a system international. Another is that the readiness of any nation to accept science findings or recommendations regarding the environment depends on the level of that country's involvement in the processes of data acquisition and analysis.

"Integrated" also implies the combination and coordination of space-based and ground-based measurements, as is required in virtually every area of environmental research, in that each of the two sources of information complements and helps validate the other. A third intended meaning is the linking of measurement technology with scientific analysis, to reap the greatest information return from what is observed and monitored.

The S for "Strategy" in IGOS is another key word. It means matching what is needed in the way of observations with existing and planned capabilities. It implies the needed forum for national and international agencies to coordinate and tailor their own commitments to meet a global goal. And unlike the "system" that was at first proposed, a strategy is open and flexible. A "system" more conventionally concentrates on defining the ultimate goal; a "strategy" starts here and now, focusing on the process of advancing toward an end that can be readjusted as new knowledge emerges.

## CONCLUDING THOUGHTS

Most people who deal with climate or other environmental issues would agree with the need to maintain a continuous watch on the planet's vital signs. It is equally clear that the observations that are required to detect significant global changes are far more diverse than what is now measured for day-to-day weather forecasts, and more continuous and systematic than what comes our way through the chance discoveries of experimental spacecraft missions and field research.

A number of obvious impediments must be overcome to create a lasting global observing system. First, public commitment and government support need to be sustained over the periods necessary to identify meaningful trends, which are often measured in decades. Moreover, unlike landing an instrument on the Moon or Mars, or finding a cure for a dread disease, there is no clear-cut “end point” to the endeavor: to separate trends from noise, and to monitor subsequent changes, observations must keep going, and going, and going. In the meantime, political parties will change power, market indices will rise and fall, and domestic and international priorities may change in response to national or geopolitical events. Yet, the example of international weather data has demonstrated that cooperative efforts of this kind in science can indeed be sustained, uninterrupted, through good times and bad, and even through international confrontations.

A second obstacle is that while the data acquired by a properly designed global observing system cannot be controversial, the issues to which they pertain almost always are. In matters that touch our lives, healthy scientific debate can be selectively taken to fuel public dissent. Strategies for coping with environmental changes involve economic choices, tensions between long-term good and short-term gain, and frictions between perceived winners and losers. While the vagaries of day-to-day weather have come to be accepted as random events, at least some longer-term climatic variations may not be. The human dimension is unavoidable--for our own actions can indeed provoke environmental changes on a global scale. To some nations or private interests, the prospect of global environmental monitoring may seem invasive and unduly provocative.

In this domain of science, there is probably no easy road to public confidence, and perhaps no crucial experiment or definitive demonstration of worth that will convince everyone, everywhere. To most thinking people, however, the way to more prudent environmental decisions and a clearer view of what lies ahead is through more systematic documentation of the general state of the planet on which we live.

### Why strive for an Integrated Observing System?

The early Greek philosophers had a fair understanding of rain, wind, and tides, and for centuries scientists have recorded natural and human-induced changes in their local surroundings. Ours is the first generation with tools to perceive the planetary dimensions of environmental change, and the first with the computational means to interpret and predict these changes on a global scale. The last thirty years have demonstrated the value of remote sensing and the feasibility and potential of international collaboration in matters of global environmental change. Beginning with the TIROS weather satellites in the 1960s, the first Landsat spacecraft in 1972, and extending through to International Earth Observing System platforms that are currently under development, nations have demonstrated a willingness to support and carry out the comprehensive observations needed to study climate and other significant changes in the global environment. It seems to us that the largest remaining challenges are no longer technical but organizational in nature.

Anticipated trends in population growth and corresponding increases in the demand for energy and other natural resources imply that the next generation and those following will need to make prudent decisions to maintain and improve the quality of human life. The formulation of well-informed policy recommendations will depend on reliable answers to questions of the sort that are all too familiar to us today: What is changing, and why? To what degree are these normal, natural variations? What are the economic and social consequences? How certain are these purported or expected trends, and with what assurance are the practical projections made?

It is our obligation, now, to systematically monitor the variables that reflect the habitability of our planet and put in place the scientific infrastructure that will make the environmental questions of the next twenty or one hundred years more answerable. We owe the next generation the scientific means to think clearly about its global environment.

END

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# FIGURES

We shall use a limited number of figures, none of which is sufficiently completed in time for this review.

# FOR FURTHER READING

Climate Change 1995: The Science of Climate Change. Summary for Policymakers and Technical Summary of the Working Group I Report; Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, England, 1996.