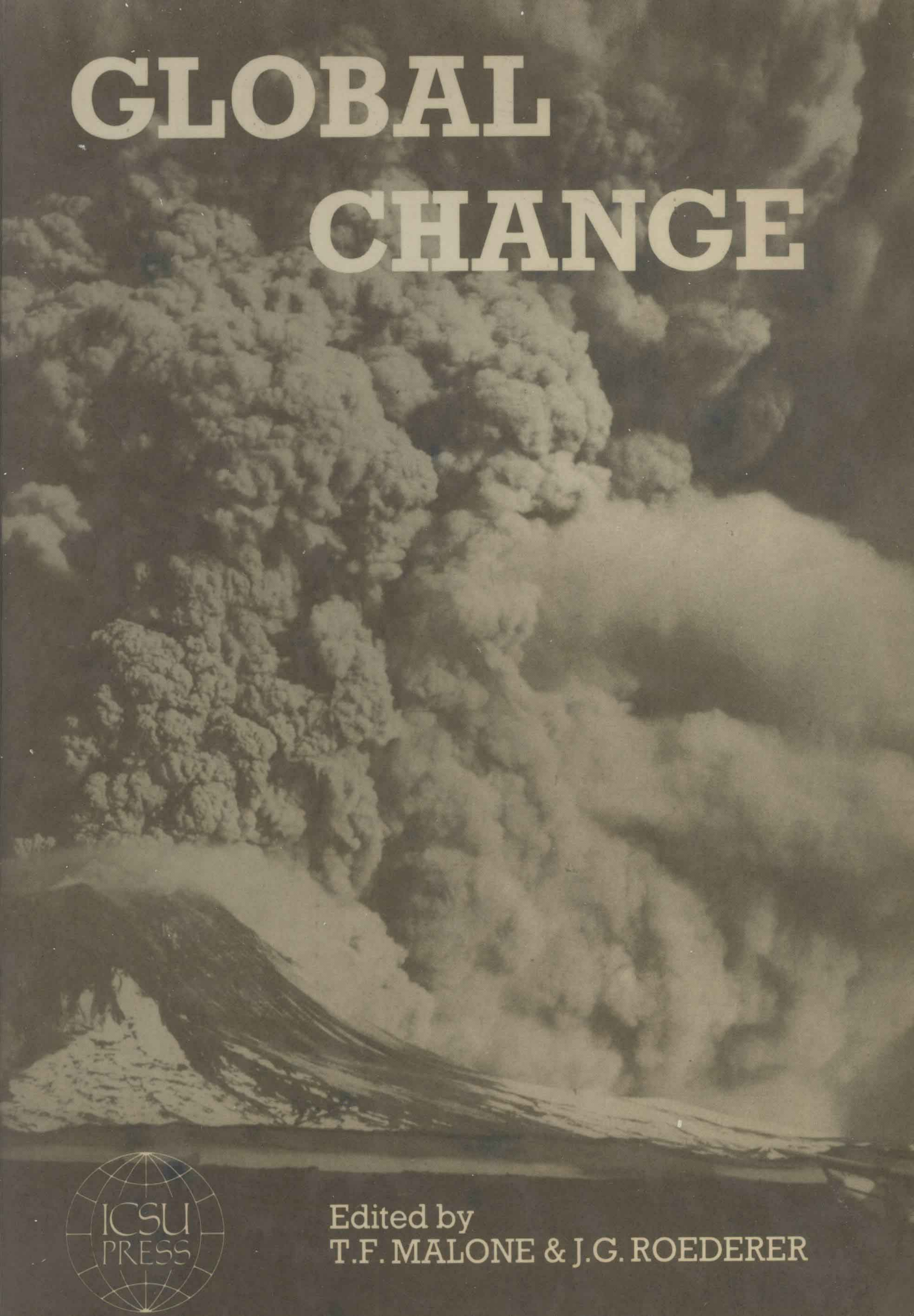
GLOBAL CHANGE



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Global Change

The Proceedings of a Symposium sponsored by the International Council of Scientific Unions (ICSU) during its 20th General Assembly in Ottawa, Canada on September 25, 1984.

Edited by:
T.F. MALONE AND J.G. ROEDERER

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The cover volcano photograph courtesy of Professor Jurgen Kienle, University of Alaska.

Introduction

John Kendrew

President, International Council of Scientific Unions

The International Council of Scientific Unions (ICSU) arranged this multidisciplinary symposium as part of its 20th General Assembly in Ottawa in September 1984.

ICSU is a federation of twenty scientific Unions, covering all the disciplines of science, and of seventy-one national academies or analogous bodies, and as such is the world non-governmental organization of scientists. The Unions represent the professional and scientific interests of workers in each field - chemistry, biology, geography, physics, etc. - arranging scientific congresses and symposia, training courses and fellowships, sponsoring scientific publications, working on problems of standardization and nomenclature - and in these days their activities are directed increasingly towards the developing world and to the fostering of measures to assist the developing countries to acquire the scientific basis that is a necessary ingredient of the process of development. Besides the Unions and the National Members, ICSU has ten Scientific Committees mounting interdisciplinary studies of interest to several of the Unions, some on a very large scale like the International Geophysical Year of twenty-five years ago, and the BIOMASS (Biological Investigation of Marine Antarctic Systems and Stocks), an undertaking of today.

ICSU's General Assembly, held each two years, is primarily an occasion when the members of ICSU - the National Members and the twenty Unions, as well as the interdisciplinary Committees - meet together to discuss priorities for future activities, to review the work of the past, and to arrange the complex administrative procedures that are a necessary part of a world-wide enterprise of very wide scope. Although General Assemblies in the past have generally included a short symposium, or a set of lectures, on scientific topics, these have been a relatively small element of the proceedings.

ICSU has come to believe that the General Assembly, at which distinguished scientists in all fields of research meet together for a week at a time, is an ideal opportunity for a more extended discussion of topics currently important in the world of science and germane to the activities of ICSU. We hope that such meetings will be valuable not only to those participating in the General Assembly, but also to the scientific and professional community in the country in which it is held and to others who may wish to attend.

We were happy to have the enthusiastic collaboration of the Canadian scientific community in arranging our first large-scale Symposium. Three subjects were chosen: gene technology, because of its great scientific importance and vast potential in industry, in medicine and in agriculture; global change - a study of both the ineluctable and the avoidable processes that are altering the environment in which we live, and of the consequences for the future of the human race; and finally the teaching of science, the principal preoccupation not only of our Committee of that name, but of many groups within the Unions, and in our view one of the principal weapons in the battle to increase the intellectual capacities of the human race as a whole and in particular to raise the scientific level of the developing world.

We thank everyone who contributed to the ICSU Symposium on Global Change, as organizers, speakers, discussants and as the audience. The deliberations are now placed in the public domain by the ICSU Press in partnership with Cambridge University Press.

Preface

Thomas F. Malone

This Symposium was intended to be the first step in a two-year systematic exploration by ICSU and its constituent bodies of the question: Is the time ripe to launch a cooperative, interdisciplinary, international program to illuminate the complex and synergistic physical, chemical and biological processes in the Sun-Earth system that determine its changes? These processes not only govern but are also profoundly influenced by living things - especially by human activity. As the number of humans increases, and their demands on the environment of a finite earth grow, a deepened understanding of anthropogenically induced global change is becoming an imperative of contemporary society.

Thoughtful and well-designed programs are already in place to study many of these processes. They constitute an important and necessary base for developing a new paradigm for research in the earth sciences: life as a planetary phenomenon.

The objective of the Symposium was not to identify or to define the elements of a new paradigm for studying the earth and its environs. The central question before us was whether it is timely to begin the development of such a concept through an international endeavor. Specifically, can we envision an assemblage of research and observational efforts that would treat the earth and its environs as a closely linked system, constantly undergoing changes on time scales from transient phenomena to the slow recurrence of ice ages? Is the intellectual challenge sufficient to devote some time and thought to this matter with the expectation that attractive research vistas would be revealed? Can these new opportunities be exploited to enhance - indeed to accelerate - the progress of ongoing programs in the earth sciences while simultaneously laying the groundwork for an integrated future attack on the problem of global change?

The Symposium papers, and the comments which are included in these proceedings, are, then, simply a starting point.

The roots of this Symposium are deep. For millenia, humankind has sought to understand the nature of the world we inhabit and the processes which determine its state at any given time. This inquiry began long before we realized the world was a planet, and that we were tenants and caretakers.

Centuries ago Aristotle began to set down some thoughts on the physical system which sustains life in his treatise on the philosophy of science and nature. Somewhat between ancient Platonism and modern idealism, Aristotelianism maintained that all things are substances (natural, supernatural and human) and all related in one way or another to each other. Of more immediate concern to this Symposium was the suggestion early in the 17th century by Francis Bacon that cooperative efforts were the best way to obtain information about the nature of the world we occupy. European nations did, in fact, mount a cooperative program to observe the transit of Venus in 1751. A subsequent transit of Venus in 1769 afforded an opportunity to link observations in the New World with those in the Old. Within a few decades a meteorological network was established from Gotthaab in Greenland to Pyshminish in Russia. Observations taken three times daily at as many as thirty-nine stations and were published in Ephemerides Societatis Meteorological Palatinae (1).

International collaboration proceeded slowly during the 19th century, initiated for the most part by an emerging set of international scientific organizations. The so-called First International Polar Year (FPY) in 1882-83, involving scientists from two dozen nations, is generally recognized as the forerunner of international, collaborative efforts to lay the observational basis for an understanding of the earth and its environs. A network of fourteen circumpolar stations provided simultaneous observations during thirteen months over a number of disciplines, including geophysics and biology. The Second Polar Year (SPY), 50 years later, involved scientists from 40 countries and led to the publication of observations and analyses in the fields of meteorology, radiation, ozone, aerology, geomagnetism, earth currents, atmospheric electricity, ionospheric physics, auroral physics, cosmic rays, hydrography, glaciology, noctilucent clouds, astronomy and some elements of biology. A byproduct of these scientific studies that is of contemporary significance was increased knowledge of the ionosphere which greatly enhanced the technology of radio-communications.

During the next two decades, the pace of scientific and technological progress was so rapid that the need and opportunity for synoptic, global, observational data and analysis became urgent. The prediction of a period of unusual solar activity in 1957-58, and the imminent possibility of an earth satellite program, prompted the scientific community to propose an "International Geophysical Year" to cover the 18-month period from July 1, 1957 to December 31, 1958. The importance of continuing the traditional attention to polar regions that had characterized the FPY and SPY was preserved by special plans to explore systematically scientific issues in the Arctic and in Antartica.

Tens of thousands of scientists from 70 nations participated in this endeavor. The IGY was so successful that it was followed by such programs as the International Year of the

Quiet Sun (IQSY), the Upper Mantle Program (UMP), the International Magnetospheric Study (IMS), the Global Atmospheric Research Program (GARP), the International Biological Program (IBP), the Man and the Biosphere Program (MAB), the International Hydrological Decade (IHD), and the International Decade of Ocean Exploration (IDOE) (2).

The rapid growth in the study of Earth, its environs, and life in the biosphere has progressed to a point where it is now possible to think seriously of fashioning a bold, holistic approach that will deepen and strengthen our understanding of the planet's subtle and often synergistic physical, chemical, and biological processes. Such a framework would examine the oceans, atmosphere, lithosphere, hydrosphere, biota, and the solar-terrestrial domain as a single system.

Three characteristics of the proposal under consideration are unique. The first is the integration of biological processes in the biosphere with the geophysics of the much larger domains of the atmosphere, oceans, lithosphere and solar terrestrial interval. The second is much greater attention to chemical processes, in particular to the biogeochemical cycles of both major and minor nutrients and contaminants. The third is the holistic framework within which the processes in the domains will be examined and their interactions assessed. All three are formidable tasks, not to be undertaken lightly. No amount of exhortation nor erudite exposition of a rationale will be decisive. It is the judgment of active researchers, particularly young scientists, that will be the determining factor.

The proposal to unite geophysics and biology is the culmination of conceptual thinking that began in 1875 with the identification of the "biosphere" - described by the Austrian geologist Edward Suess - as the concentric, life-supporting layer of the primordial Earth. It has been developed as a concept in modern scientific thought largely through the work of the Russian mineralogist, V.I. Vernadsky during the 1920's. He characterized the biosphere as the terrestrial envelope embracing the troposphere, the hydrosphere or oceans, and the continental layer extending several kilometers below the surface of the earth. Its unique properties were prevailing conditions that enabled incoming solar radiation to produce the geochemical changes essential for the genesis and continued existence of life forms. He stressed the inextricable linkage between life and its surrounding energetic and material structure through photosynthesis, transpiration and nutrition (3).

We are apparently on the threshold of developing a new paradigm by which the processes governing the behavior of this system are defined and identified (4). For example, Lovelock has postulated the existence of an encompassing living feedback system through which the biosphere regulates the physical environment by and for itself as external stimuli change - the Gaia hypothesis (5).

Four reasons suggest that "the time is ripe to set up and expand current efforts to understand the great interlocking systems of air, water, and minerals nourishing the Earth" (6). The first is the growing realization - from the more or less independent studies of the atmosphere, oceans, crustal dynamics, life-supporting ecosystems, and solar-terrestrial relations - that the biotic and nonbiotic components of the biosphere are inextricably intertwined. For example, the global issue of climate is now correctly perceived to be as much an oceanographic problem as a meteorological one (7). Moreover, the illuminating studies of ICSU's Scientific Committee on Problems of the Environment (SCOPE) on biogeochemical cycles have clearly demonstrated the "far-reaching consequences at all ecosystem levels, both in marine and terrestrial systems", of these processes (8).

Improved understanding of the pathways and rates of exchange for the primary constituents of living organisms (carbon, nitrogen, phosphorus, sulfur, hydrogen, and oxygen) and their relation to the other great domains of planet Earth have taken on a "special urgency" (9). Only as recently as 1981 was W.S. Fyfe, Professor of Geology at the University of Western Ontario, able to make the unchallenged statement that "the significance of the exchange processes of the outer systems of the Earth, oceans, atmosphere, biomass, sediments and rock is obvious" (10).

A second reason for creating an international collaborative effort is that human impacts have grown to approximate those of the natural processes that control the global life-support system. The sagacious words of Harvard Professor Richard Goody and his colleagues at a workshop of scientists who met in Woods Hole, Massachusetts, in July 1982 set forth the case eloquently:

> The human race lives on a planet characterized by change .... This is a unique time, when one species, humanity, has developed the ability to alter its environment on the largest (i.e., global) scale and to do so within the lifetime of a single species member (11).

Climatic change resulting from increased anthropogenic carbon dioxide in the atmosphere, acid deposition, deforestation, and desertification are all examples of this phenomenon.

A third reason for the necessity of studying the link between biological and geophysical processes rests with the inexorably growing demand in developing nations for sharply enhanced biological productivity. In the coming years, humanity will have to respond to the imperative for increasing access to the food, fiber, energy, and shelter required by the rapidly growing global population. For example, it is estimated that the population of the Third World will increase by 2 billion people between 1975 and 2000.

Finally, a rapidly advancing technological base has brought within reach the capacity to complete the triad of theory, observation, and data management that must underlie an international collaborative effort - one that will extend the imagination and capacity of the world's scientific community to its limits. An incredible array of observational tools is now within reach, from the numerous different satellites that provide global surveillance, to chemical techniques that measure substances in parts per trillion. The sophistication of communications technologies, the capacity of computers, and the methodology of systems analysis have literally exploded in recent years. Such advances have brought within real time the analytical, data-handling, and data-management techniques required to respond to a sharply focused set of questions concerning the interaction of the Earth's life-sustaining physical, chemical, and biological processes.

It is within this context that one can consider initiatives that have been proposed to address the scientific challenge and opportunity before us. First of all, however, it should be clearly understood that no "super program" is envisaged that would subsume national and international research programs currently underway or in the planning process. They must be vigorously pursued as independent, but closely related, efforts that constitute the base from which increasing emphasis on the processes which connect them can be structured. These programs include:

TOGA, which seeks to study the interannual variability of the Tropical Oceans and Global Atmosphere:

WOCE, the World Ocean Circulation Experiment, whose principal goals are:

> To determine the three dimensional general circulation of the ocean over a period of several years, its annual cycle and long-term variability;
>
> To determine the major elements of the oceanic flux of heat and fresh water and to estimate the conversion rates of water within the oceans;

WCRP, the World Climate Research Program, which is aimed at determining the predictability of climate and the extent of anthropogenic influences on climate, using, *inter alia*, physical-mathematical models capable of simulating climatic changes over a wide range of space and time scales;

ISTP, the International Solar-Terrestrial Program, proposed collaboratively by the European Space Agency, the Japanese Institute of Space and Astronautical Science, and NASA (12):

> To study the internal behavior and structure of the sun, its emissivity and variability in several spectral ranges;
>
> To examine the emission of energetic and solar wind particles and their interaction with, and effects on, the earth's environment;

ILP, the International Lithosphere Program which builds upon the scientific achievements of the Upper Mantle Program and the International Geodynamics Project to elucidate the nature, dynamics, origin and evolution of the lithosphere, with special attention to the continents and their margins. Closely related is the IGCP, the International Geological Correlation Program, which seeks to encourage international research on geological problems related to the identification and assessment of natural resources and the improvement of man's environment. The emerging subject of seismic tomography - a technique that promises to make possible mapping of the three dimensional structure (temperature, composition and convection) of the deep interior of the Earth - is likely to advance significantly the new paridigm of plate tectonics that has influenced solid earth geophysics since it gained acceptance more than two decades ago.

MAB, the Man and Biosphere program includes the continuing issues (13) of:

> The search for sustained production systems in the humid and subhumid tropics, zones under rapid change and increasing pressure as a source of enegy;
>
> The scientific basis for management of grazing and marginal lands, by their very nature fragile and likely to be increasingly menaced in the near and medium-term future;
>
> Providing a better basis for ecosystem conservation as a programmatic response to linking conservation with development and to the world population growth expected by the end of the century.

Major impetus to this Symposium was provided by Professor George Garland (Past President of the International Union of Geodesy and Geophysics) in a lecture commemorating the 25th anniversary of the International Geophysical Year (IGY) at the 1982 General Assembly of ICSU in Cambridge, England, when he remarked:

> "Today we have a reasonably complete understanding of the links between physical processes affecting our planet and the region around it. Many of the mysteries which remain involve the interaction between these physical processes and biological material, including man himself. Indeed, further progress in some of these areas requires the expertise of literally every discipline now represented in ICSU .... This will not only present a challenge to all of the disciplines now represented in ICSU but will require increasing contact with organizations involved with the human and social sciences" (emphasis added).

A similar concept was proposed by Dr. Herbert Friedman, Chairman of the Commission on Physical Sciences, Mathematics, and Resources of the National Academy of Sciences at the Annual Meeting of the Academy in 1983 where he called for a bold, holistic venture in global research - the study of whole systems of interdisciplinary science in an effort to understand global changes in the terrestrial environment and its living systems.

The General Committee of ICSU reviewed this matter at its 1983 Meeting in Warsaw, Poland and voted:

> "...to establish an ad hoc committee to carry out the study of those aspects of global change which are not yet adequately covered, to prepare an inventory of existing programmes and their inter-relations, and to make recommendations to the 20th General Assembly for further planning in fields that are interdisciplinary and require international cooperation."

An organizing committee with Thomas F. Malone and Juan G. Roederer as Co-Convenors was established and a meeting was held in Paris in November of 1983 to plan this activity for the 20th General Assembly. This group remarked, in part:

> "A central intellectual challenge of the next few decades is to deepen and strengthen our understanding of the ... interactions between the several parts of the geosphere and biosphere. This knowledge base underpins societal management of our global life support system to enhance biological productivity and to respond to the increasing needs of a growing population.
>
> Augmentation of established national and international programmes will be required to illuminate the processes that govern the behaviour of the oceans, atmosphere, lithosphere, biosphere and the solar terrestrial domain by addressing the interfaces among them. ...several years of

> careful planning and conceptualization (will be required) to develop an appropriate scientific strategy. In view of the need to pursue and support existing programmes... the decade of the 1990's appears to be an appropriate period for the proposed international programme."

During ICSU's 1984 General Assembly in Ottawa, Canada, the first step was taken in a process that will involve the world scientific community through ICSU's 20 disciplinary Unions, interdisciplinary Committees, and National Members over the next two years. The General Assembly unanimously approved exploration of the "... interaction between the physical and living world ..." a concept variously known as "Global Change" or "International Geosphere-Biosphere Program." A series of workshops was recommended in Symposium papers to define sharply focused programs which, it is expected, will lead to the presentation of a sound scientific strategy at the 1986 General Assembly of ICSU in Switzerland. The urgency of moving from the "crisis of the month" approach in atmospheric chemistry (e.g., carbon dioxide and methane buildup, acid deposition, ozone depletion) to capitalizing on an explosively developing illumination of atmospheric chemistry in order to establish a comprehensive scientific framework for dealing with these crises underscores the need to elucidate the interplay of chemical and biological processes which have received less emphasis than physical processes in present programs (14).

The new dimensions of collaborative research that are likely to be given particular attention in the planning process over the next two years will include:

- Attention to the biogeochemical cycling of the major (and minor) nutrients that support biological productivity (i.e., carbon, nitrogen, phosphorus, sulfur, and water) as an example of focus on interface studies.

- Gradual structuring of a world-wide biological monitoring system that will possess intrinsic scientific merit and provide the necessary "ground truth" to develop the powerful global monitoring capability of remote sensing;

- Development of what I. Rasool (15) terms "a more programmatic approach" by which the international space science community can effectively organize itself for a productive interaction with other parts of the world scientific community. Steps include:

(i) Sensor calibration of the various satellites;
(ii) Uniform correction methods for sensor drifts;
(iii) Common methodology for retrieval of physical parameters from the measured radiances;
(iv) Inter-satellite comparability;
(v) Uniform procedures for cloud and atmospheric correction;
(vi) Validation of satellite derived information with surface data.

Clearly new modalities of interagency collaboration activity will be required (The ISTP proposal is an interesting beginning).

- Fashioning a modern data-management system that will be responsive to the needs of scientists wherever they may be. Data management problems could severely limit the research that can be done using remote-sensed data. Present capacity to collect data about the Earth and its environs exceeds the capacity of the world scientific community to assimilate those data. Careful design of measurement programs and foresight in planning for the effective utilization of powerful communications and computer technology will be required.

The community of space agencies has been alert to its important role in the activities envisioned here. At the 1982 United Nations Conference on the Peaceful Uses of Outer Space (UNISPACE), NASA proposed an international cooperative program to address natural and anthropogenic changes affecting the habitability of Earth. Called "Global Habitability", the program is intended to focus on the water, biogeochemical, and energy cycles which comprise the life support systems of the global habitat (11, 16, 17, 18).

The next two years provides an excellent period for the various ICSU bodies to examine the potential of an international program on Global Change. Special workshops may be required to design timely programs. Timeliness is critical. As F.M. Cornford of Cambridge remarked in the early part of this century, there is only one argument for doing something - the rest are arguments for doing nothing. He warned against "The Principle of Unripe Times which persuades people not to do ... at the present moment what they think right of that moment, because the moment of which they think it right has not yet arrived". He added that "Time, by the way, is like a medlar; it has a trick of going rotten before it is ripe" (19).

The century since the first Polar Year has seen a phenomenal increase in our knowledge of Planet Earth and its Environs. We now stand -- on the shoulders of our predecessors -- on the threshold of a revolution of historic proportions on human understanding. The vantage point from space provides a leverage that makes possible a quantum leap. The intellectual challenge of acquiring deeper understanding is equalled by the promise of utilizing that understanding in shaping human destiny over the critical next millenium. The prospects for a new and better kind of human future, both on and off Planet Earth, have never been brighter.

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Special note should be taken of the initiative of Past President George Garland of the International Union of Geodesy and Geophysics for suggesting a program of this kind in his 1982 Commemorative Lecture on the IGY. Dr. Herbert Friedman has been a continuing source of inspiration and encouragement, as well as indefatigable in laying the groundwork for this effort.

Appreciation is expressed to those participants who submitted comments or papers which were not included because they overlapped material in these proceedings.

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Thomas F. Malone
Juan G. Roederer