4.2 On the NASA Earth Observing System

The Space Studies Board sent the following letter and attached position to Adm. Richard H. Truly, Administrator of NASA, on July 10, 1991.

We are pleased to transmit to you two new Space Studies Board reports:

Space Studies Board Position on the NASA Earth Observing System, and a prepublication copy of a related report, *Assessment of Satellite Earth Observation Programs—1991*, by the Board's Committee on Earth Studies. We will forward a bound copy of the latter report as soon as it is printed.

Copies of these reports will be sent to cognizant executive agency and congressional offices tomorrow morning and subsequently to the media. Do not hesitate to call me if you have any questions about either of these reports.

Signed by
Louis J. Lanzerotti
Chair, Space Studies Board

SPACE STUDIES BOARD POSITION ON THE NASA EARTH OBSERVING SYSTEM

Introduction

Complex scientific questions and major policy issues together provide the motivation for a comprehensive attempt to improve our understanding of the earth system. Progress in the scientific disciplines concerned with the Earth and its evolution on time scales of decades to centuries has revealed critical questions that can be resolved only by studying the entire system, concentrating especially on interdisciplinary questions that reflect the complex interactions among the system's components. Policy issues arise because human activities and natural processes are changing the environment in ways that may be significant to the future health and habitability of the Earth. The scientific and policy issues have been well documented in a series of National Research Council (NRC) and government reports over the past decade.

These factors and the need for accurate and comprehensive scientific information on which to base environmental policy decisions have led to the creation of a number of international and national research initiatives, including the U.S. Global Change Research Program. According to the report *Our Changing Planet: The FY 1992 U.S. Global Change Research Program*, by the federal interagency Committee on Earth and Environmental Sciences (1991),

> The central goal of the U.S. Global Change Research Program (USGCRP) is to establish the scientific basis in support of national and international policy making relating to natural and human-induced changes in the global Earth system by:

- Establish[ing] an integrated, comprehensive, long-term program

of documenting the Earth system on a global scale.
• Conduct[ing] a program of focused studies to improve our understanding of the physical, geological, chemical, biological and social processes that influence Earth system processes; [and]
• Develop[ing] integrated conceptual and predictive Earth system models. (p. 1)

Even before the creation of the USGCRP in 1989, these considerations motivated the community of earth scientists concerned with global change to develop plans for research, observation, and modeling activities to improve scientific understanding. At the center of this set of activities was the Earth Observing System (EOS), a major initiative that has now been incorporated into the USGCRP. As currently proposed, EOS will involve a number of spacecraft carrying instruments designed to produce, across a wide spectrum of electromagnetic frequencies, detailed observations of the physical variables that reveal the state, evolution, and interactions of the atmosphere, oceans, and land surface, as well as the biological communities on the land and in the sea. The EOS program is planned to span almost two decades, beginning with the launch of the first spacecraft in 1998. It will generate unprecedented amounts of data that must be converted into information and understanding, and ultimately, used to develop techniques for prediction. These complex data management functions will be performed through the EOS Data and Information System (EOSDIS), which will provide computing and networking facilities for research; processing, distribution, and archiving of EOS and related data; and spacecraft command and control functions. In addition to developing the flight components and the EOSDIS, the EOS program also supports interdisciplinary research teams, 28 of which are already established, to study focused issues that range across the relevant earth-related sciences. Other nations, notably Japan, Canada, and the member states of the European Space Agency, have made commitments for significant contributions to the total EOS program, including instruments and ground facilities. In short, EOS, as currently planned, will be the largest single component of the most ambitious scientific enterprise ever undertaken.

Nevertheless, there are observations critical to understanding the earth system that cannot be obtained by the instruments proposed for the polar-orbiting, sun-synchronous EOS spacecraft. Thus EOS itself is considered by NASA to be part of a broader satellite remote sensing initiative-Mission to Planet Earth-that will augment EOS with a number of focused missions, called Earth Probes, in other orbits. Possible missions under consideration include measurements of the Earth's radiation budget, an accurate determination of global land-surface topography, synthetic aperture radar observations of the Earth, and measurements of the Earth's gravity and magnetic fields. NASA plans that Mission to Planet Earth will eventually include geosynchronous satellites taking continuous synoptic observations of the planet. Several other NASA research missions being prepared for launch prior to the EOS time frame, such as the Upper Atmosphere Research Satellite and the Ocean Topography Experiment (TOPEX/Poseidon), also will make important contributions to our understanding of the Earth.

These elements of NASA's Mission to Planet Earth are or will be augmented significantly by the operational environmental spacecraft of the National Oceanic and Atmospheric Administration (NOAA) in polar and geostationary orbits, by the Landsat system operated on a commercial basis by the Earth Observation Satellite (EOSAT) Company, as well as by certain declassified data from operational and experimental satellites of the Department of Defense. Internationally, there are numerous experimental, operational, and commercial spacecraft already in orbit or under construction by the European Space Agency and its individual member states in western Europe, and by Canada, Japan, the Soviet Union, China, and India that can be expected to contribute to the global research and monitoring effort.

Scientific Significance of the EOS Program

The scientific questions motivating and shaping studies of the Earth generally, and the EOS program specifically, are very challenging. They are different in some respects from the questions that motivate much of space research, for they concern the behavior of an entire complex system, the role of feedback and interfacial processes in controlling its evolution, and the development of parameterizations that can be used to make long-term statistical projections. It will take several decades, at least, to answer these questions with confidence, even though the elements of critical policy issues may become clear much sooner.

Based on the research priorities established by the earth science research community, NASA (1991) has articulated the following specific measurement objectives for EOS in the *EOS Reference Handbook—1991*:

- Global distribution of energy input to and energy output from the Earth.
- Structure, state variables, composition, and dynamics of the atmosphere from the ground to the mesopause.
- Physical and biological structure, state, composition, and dynamics of the land surface, including terrestrial and inland water ecosystems.
- Rates, important sources and sinks, and key components and processes of the Earth's biogeochemical cycles.
- Circulation, surface temperature, wind stress, sea state, and the biological activity of the oceans.

- Extent, type, state, elevation, roughness, and dynamics of glaciers, ice sheets, snow, and sea ice.

- Global rates, amounts, and distribution of precipitation.

- Dynamic motions of the Earth as a whole, including both rotational dynamics and the kinematic motions of the tectonic plates.

Not all of these scientific objectives will be fully addressed in the EOS program, however. These and other deficiencies in the planned observations are discussed in the Space Studies Board's Committee on Earth Studies report, *Assessment of Satellite Earth Observation Programs—1991* (Space Studies Board, 1991), as well as in *The U.S. Global Change Research Program: An Assessment of FY 1991 Plans* (National Research Council, 1990).

In addition to the many contributions to the traditional earth sciences now expected, the EOS program will have other significant impacts. It will stimulate the development of the new earth system science that transcends today's discipline-specific emphasis on components of the earth system and that produces a truly global view and comprehensive understanding of our planet. There will be strong impacts on the evolution of biological and ecological sciences, because the development of explicit models of the interaction of biological systems with the physical environment will be pursued. The EOS program is designed to provide an empirical base of information about the distribution and large-scale evolution of biological systems that may be expected to inspire the development of a theoretical understanding of macroscopic biology.

Moreover, understanding the interactions of all the components of the earth system could provide a prototype for the development of a theory of dynamical systems considerably richer than is now available. Among the most interesting issues are the interactions of processes on diverse spatial and temporal scales, the origins of catastrophic transitions between quasi-stable states of the system, and the characteristics of a system that determine its limiting behavior. The earth system models that will evolve from global data are also expected to stimulate the development of techniques for predicting the statistics of chaotic states for which deterministic prediction is impossible. Finally, the earth system computer models used to simulate future climate patterns and other large-scale processes will permit socioeconomic studies that require quantification of human interaction with the environment.

EOS in the Broader Context

As proposed, EOS is of unprecedented complexity and magnitude for two reasons. First, meeting the scientific requirements to observe and understand the interactions of earth system components requires integrated, and in some cases

simultaneous, measurements of suites of variables. Thus the science requirements mandate spatially comprehensive observations of the Earth that produce information relevant to a broad spectrum of questions. Second, the importance of the policy issues associated with the possibility of accelerating global change requires that many elements of the observation program be developed through parallel, rather than incremental, endeavors. This approach must be managed with both innovation and rigor to ensure that each component of the proposed EOS program will be successful and that the program will achieve its objectives within a reasonable and well-defined cost.

Even so, the resources for EOS, as currently proposed, could become a significant fraction of the nation's civil space research program. There is an obvious danger that other important U.S. research initiatives may be compromised by the demands of EOS. The board notes that a 1988 NRC report, *Toward a New Era in Space-Realigning Policies to New Priorities*, and the *Report of the Advisory Committee on the Future of the U.S. Space Program* (NASA, 1990) both recommended that major NASA programs such as EOS and the human exploration of space be considered and evaluated as additions to a base space research effort. The SSB reaffirms this recommendation.

The national resources required to execute the proposed EOS program will be considerable, and there must be confidence that the investment will produce the achievements that are now expected. The EOS program will provide information and knowledge that could be used to address a number of concerns related to national well-being. The EOSDIS, in particular, will provide the capability to synthesize information for a broad range of applications, including the preservation of diverse ecosystems, the enhancement of agricultural productivity, and the improved management of our natural resources. The EOS program can help strengthen national and global security, in part because it will provide a significant portion of the scientific basis with which to address the potentially contentious political and economic issues related to human influences on global change, and in part because it will draw scientists and others from around the world to work in concert to understand, preserve, and perhaps improve our environment.

There are other benefits that could flow from EOS. It will stimulate the development of technological capability and new approaches to the management of large and complex collections of data and information. As an international effort, EOS can symbolize U.S. leadership in addressing global environmental problems. The sensors of the EOS program that are aimed at studying the Earth's surface and troposphere can augment current operational spaceborne systems. The necessary interfaces of the EOS program, with the relevant government agencies and the appropriate private-sector users, must be an integral part of EOS program planning if the broader applications of EOS data are to be realized. Given the planned long duration of the EOS program, such sensors may in some cases become the operational systems of choice, once their capabilities have been demonstrated.

Conclusions and Positions

The Space Studies Board (SSB) position on the EOS program is based in part on an analysis performed by its Committee on Earth Sciences (CES) in an unpublished internal report to the board, as well as on the committee's full report, *Assessment of Satellite Earth Observation Programs—1991* (Space Studies Board, 1991). This assessment by the board also takes account of the conclusions and recommendations described in *The U.S. Global Change Research Program: An Assessment of FY 1991 Plans* (National Research Council, 1990), and other previous reports of the SSB and the NRC cited in the bibliography.

In conducting this review, the SSB did not evaluate the cost-effectiveness of the proposed EOS program or compare it to other potential options. The board accepts the conclusions and recommendations on these issues made in the report, *The U.S. Global Change Research Program: An Assessment of FY 1991 Plans*, in the preparation of which members of the board and its Committee on Earth Studies played an active part. The board notes as well that questions of cost and comparisons to other mission scenarios are currently being independently reviewed by the Earth Observing System Engineering Review Advisory Committee, at the request of the Office of Management and Budget.

The conclusions and positions presented in this position paper simultaneously inspire confidence and generate concern. Clearly, the planners of the EOS program are attempting to incorporate the advice and key recommendations of the research community. As it now stands, the program serves well the scientific strategies recommended by the SSB and other advisory bodies. But EOS is an immense undertaking, and there are aspects of it that are not, and cannot be, completely determined or envisioned now. The flight configurations and the design of the data and information system are not yet fully defined. Moreover, the management of EOS must be sufficiently flexible to take advantage of continuing evolution over the program's lifetime in scientific understanding and requirements, and in technological capabilities. There is concern that the present program does not institutionalize such flexibility. The scope of the program will require the development and implementation of sophisticated and innovative management principles and structures at the project, agency, interagency, and international levels. These issues are all significant, because answers to the scientific questions that drive EOS are central to understanding, and possibly ameliorating, global change and its impacts.

The Space Studies Board concludes that the EOS program is a potentially valuable initiative to serve the best interests of science and the nation. The component parts of EOS together address complex scientific questions whose answers are important for establishing the most effective and appropriate policies related to global change. Because of the high priority of the overall science objectives that will be addressed by the EOS program, the rationale for flying suites of instruments that will measure these objectives, and the potential importance of the effects of global change on humanity, the SSB endorses the

program. The acquisition of a long-term, continuous, and integrated series of data on the components of the earth system and their interactions is the critical scientific motivation for EOS.

Nevertheless, many important issues regarding EOS still exist and must be satisfactorily addressed in the months and years ahead. These concerns are related to matters involving (1) the development of the spacecraft configurations required for acquisition of the scientific data; (2) the design and evolution of the data and information management system; and (3) the long-term management plan to ensure program success for the planned scientific, applications, and policy purposes. After reviewing the documents prepared by the Committee on Earth Studies and the other reports cited above, the board has adopted the following conclusions and positions at this time:

- While parts of the EOS program require substantially more definition than is available at present, the SSB concludes three things about the planned implementation. First, a set of integrated instrumentation directed toward the highest-priority science is required. Second, scientific and technological evolution in the program must be implemented in a way that preserves the long-term continuity of the measurements. Third, the instrumentation selected for development for the second series of spacecraft proposed by NASA should be justified by the scientific objectives, but NASA should consider the optimum spacecraft and orbit configuration in light of all the scientific requirements.

- NASA and the scientific community should continue to examine the conceptual and architectural structures for the EOS Data and Information System (EOSDIS) to ensure that it will effectively serve the science and applications communities, that it will stimulate research and education in the sciences concerned with global change, and that it will be configured to take advantage of evolving technological capabilities.

- NASA and other entities of the federal government should give continuing attention to the optimum structures and policies for managing the EOS program. The scope and significance of the program, as well as its role as a key component of the U.S. Global Change Research Program, present a major management challenge. As it develops and proceeds, EOS can be strengthened through continuing review by the earth science and space research community.

- Management of the EOS program should institutionalize the flexibility necessary to accommodate evolution in understanding of the key scientific questions, and in technological capabilities for observation of the Earth from space. A process should be established so that EOS can take advantage of changes in spacecraft designs, instruments, and telemetry and communication systems, as well as in the hardware and software used in the data and information system, without sacrificing the central objective of collecting long-term, continuous data sets.

Planning for EOS should continue to take specific account of the possibilities of failure in the components of the flight and communication systems. The EOS architecture and design should provide sufficient redundancy and flexibility to create alternatives that can be activated to mitigate the effects of failures and provide for continuity in observations. Provisions should be considered for in-flight reprogramming of the critical parts of spacecraft, instruments, and onboard control and data systems.

The federal Committee on Earth and Environmental Sciences should carefully exercise its responsibility to ensure that EOS is integrated with the other components of the U.S. Global Change Research Program and other relevant federal programs, including the operational satellites of the National Oceanic and Atmospheric Administration, to maximize the effectiveness of all aspects of the research.

Much more attention should be devoted to the issue of how to transfer the new scientific understanding to the federal and private organizations that will develop, and be affected by, policy decisions that might arise from the research results. In particular, NASA should ensure that the EOSDIS is designed and organized to facilitate dissemination of the knowledge gained from EOS to federal agencies and private organizations, and should assist in the effective conversion of this information into sound policy decisions.

NASA should encourage the use of appropriate EOS data for applications in the operational and private sectors once the sensors have been validated in flight, and initial planning should involve those sectors. Research into the applications that will be made possible with the information derived from the new suite of EOS sensors should be supported by NASA and other federal agencies involved in such applications.

The EOS initiative must be viewed not as a project to construct and launch a number of spacecraft, but as a process to create a national and international capability for observing the Earth and providing the data and information necessary to address critical scientific questions. A number of important unresolved issues involving EOS science and system configuration still remain. The Space Studies Board will therefore continue to review the EOS program as it progresses.

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