PB88-101027

Critical Issues in NASA (National Aeronautics and Space Administration) Information Systems

National Research Council, Washington, DC

Prepared for

National Aeronautics and Space Administration
Washington, DC

Jun 87

U.S. Department of Commerce
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PB88-10 1027

Critical Issues in NASA Information Systems

Final Report to the National Aeronautics and Space Administration

Committee on NASA Information Systems
Board on Telecommunications-Computer Applications
Commission on Engineering and Technical Systems
National Research Council

BIBLIOGRAPHIC DATA SHEET

1. Report No.

2.

3. Recipient's Accession No. PB88-101027

4. Title and Subtitle
CRITICAL ISSUES IN NASA INFORMATION SYSTEMS (FINAL REPORT)

5. Report Date
June 1987

6.

7. Author(s)
NASA Information Systems Committee Members

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
National Research Council
Board on Telecommunications and Computer Applications
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

10. Project/Task/Work Unit No.

11. Contract/Grant No.
NASW-4124

12. Sponsoring Organization Name and Address
National Aeronautics and Space Administration
NASA Headquarters
Code E
Washington, D.C. 20546

13. Type of Report & Period Covered

14.

15. Supplementary Notes

16. Abstracts
The National Aeronautics and Space Administration has developed a globally-distributed complex of earth resources data bases since Landsat I was launched in 1972. NASA envisages considerable growth in the number, extent, and complexity of such data bases due to the improvements expected in its remote sensing data rates and the increasingly multidisciplinary nature of its scientific investigations. Work already has begun on information systems to support multidisciplinary research activities based on data acquired by the Space Station complex and other space-based and terrestrial sources. In response to a request from NASA's former Associate Administrator for Space Science and Applications, the National Research Council convened a committee in June 1985 to identify the critical issues involving information systems support to space science and applications. The Committee has suggested that OSSA address four major information systems issues: centralization of management functions, interoperability of user involvement in the planning and implementation of its programs, and technology.

17. Key Words and Document Analysis. 17a. Descriptors

Compact diskread-only memory	Configuration control	Data base management systems
Data compression	Data systems	Digital communications
Digital magnetic recording	Information systems	Interoperability
Management	On-line data catalogs	Software
Standardization	Standards	Technologies

17b. Identifiers/Open-Ended Terms

Committee on Data Management & Computation	Corporation for Open Systems
Digital technologies	Earth Observing System
Earth System Sciences Committee	Information Systems Office
NASA Corporate Strategies	Open Systems Interconnection
Space Physics Applications Network	Science and Applications Information System

17c. COSATI Field/Group

18. Availability Statement
Board on Telecommunications and Computer Applications
See Attachment

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page) UNCLASSIFIED

21. No. of Pages 68

22. Price A04 13.95

Critical Issues in NASA Information Systems

Final Report to the National Aeronautics and Space Administration

by the Committee on NASA Information Systems
Board on Telecommunications-Computer Applications
Commission on Engineering and Technical Systems
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C.
June 1987

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors, according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

This is a final report of work supported by Contract No. NASW-4124 between the National Aeronautics and Space Administration and the National Academy of Sciences.

This document available from:

Board on Telecommunications and Computer Applications
Commission on Engineering and Technical Systems
National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Printed in the United States of America

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PREFACE

This report concludes a study that was requested in late 1985 by the Associate Administrator for Space Science and Applications, National Aeronautics and Space Administration (NASA). In early 1986 the National Research Council's Board on Telecommunications and Computer Applications established a Committee on NASA Information Systems to perform the requested study. The original charge to the Committee on NASA Information Systems is given in the Statement of Task on page vii of this report. The Associate Administrator for Space Science and Applications provided further guidance on April 2, 1986, during the Committee's inaugural meeting. From this emerged a corollary tasking which the Committee interpreted and applied as follows:

> The Committee should look beyond the technical aspects of this study and identify the critical issues affecting how NASA's Office of Space Science and Applications (OSSA) should organize its information systems functions and programs to support space science and applications.

The Committee made every effort to respond to this verbal tasking without letting its effort devolve into a management review. Although no records were kept of the time spent on the technical or management portions of the study, it is clear that management-related matters occupied more time during the Committee's deliberations--and resulted in more heated debate--than did those related to interoperability, technology, or user requirements.

The Committee's inaugural meeting was held on April 1 and 2, 1986, in Washington, D.C. It received briefings from NASA Headquarters, Goddard Space Flight Center (GSFC), and Jet Propulsion Laboratory (JPL) personnel on current and future data management activies, including some rather detailed expositions on cataloging, data format standards, and the technical aspects of interoperability. In addition, the Committee received a briefing and verbal guidance from the Associate Administrator.

The second meeting was held on May 26-28, 1986, in Pasadena, California, hosted by the JPL, a two-and-one-half day meeting. The principal focus was on JPL's science and information systems programs, although some time was also spent on GSFC's emerging Earth Observing System (EOS) program.

A special, one-day meeting was convened on June 12, 1986. This gave the Committee the opportunity to receive briefings from the NASA Office of Space Tracking and Data Systems (OSTDS) and the National Oceanographic and Atmospheric Administration (NOAA), along with several other NASA Headquarters and GSFC briefings on significant programs and activities.

The Committee held a one-week workshop the week of July 13, 1986, in Snowmass, Colorado, to begin work on this report. In addition, the Chairman of NASA's Committee on Earth System Sciences provided a briefing that stressed the increasing interdisciplinary and multidisciplinary nature of the requirements being imposed by the science community.

The wrap-up meeting was held on August 26-27, 1986, in Washington, D.C. An informal progress report was given to the Associate Administrator on September 3, 1986.

During this study, the Committee reviewed OSSA's charter, organization, activities, and its derived set of information systems programs that require funding and manpower resources. The Committee recognizes that the OSSA charter is based on the Space Act of 1958, as amended, which established NASA. Each of the programs and functions supported within OSSA likewise can be traced to the charter. This represents both a charter and a mandate to promote the space science and applications mission.

Some of the Committee's findings and recommendations were reached independently in earlier reports from other high-level committees of the National Research Council and NASA. They are included in this report because the Committee thinks they are important and need further attention by NASA and OSSA.

Although considerable ground was covered by the Committee, this could not be an in-depth study, due to the relatively short time available. In addition, the committee found that some key personnel could not be available for our scheduled meetings due to the press of other business, stemming mainly from loss of the Challenger space shuttle and the budget problems that followed in the wake of the Gramm-Rudman Act. Any follow-on study will have to dig much deeper into the underlying aspects of the issues, and sufficient time should be allocated for such an effort.

During the course of this study, the Committee received assistance from a number of people at NASA Headquarters, GSFC, and JPL. I take this opportunity to express my gratitude to everyone who helped us. Thanks are also due to the members of the Board who contributed to the development of a final structure for this report. I particularly want to express my appreciation to Richard B. Marsten and Burton Stuve for their assistance throughout the study and especially their work in preparing this report for publication. We also thank Ms. Stephanie White for her assistance during the July workshop and the August wrap-up meeting.

Finally, I wish to give special thanks to the members of the Committee for their arduous and painstaking study of the complex and sensitive matters related to the issues covered in this report.

ADRIAN M. McDONOUGH
Chairman

STATEMENT OF TASK

The National Aeronautics and Space Administration (NASA) has developed a globally-distributed complex of earth resources data bases since Landsat 1 was launched in 1972. NASA's current program and plans for the future envision great growth in the number and extent of such data bases. The NASA program includes the development of a Global Resources Information Database (GRID) jointly with the United Nations Environmental Programme (UNEP), and eventual incorporation of the GRID into a global resources information system. Work has begun on pilot information systems in climate, ocean, planetary, and land data as the first components to support a variety of extant, geographically dispersed data bases in support of a future earth observing platform. A major future activity will be the development of information systems to support multidisciplinary research activities based on data acquired by the Space Station complex and other space-based and terrestrial sources.

The Committee's initial task will be to identify critical issues on which NASA must act to ensure that its information systems activities lead to interoperable systems with a minimum of standardization, while providing for adaptability and growth. In its review, the Committee will comment on aspects of data base design, structure, organization, and operation that could affect interoperability and the need for standards. The Committee will review NASA's existing and planned data bases in science and in applications, including pilot systems, and it will review NASA's plans for continuing data base development and the status of other information systems and data bases.

In considering the requirements for interoperability and standardization of data base characteristics, the standardization criteria for interoperability will be kept to the minimum necessary to accommodate the rapid and continuing growth of data base systems. Accordingly, the Committee will consider data base sensitivity and adaptability to changes, including those that could be introduced by possible Space Station data acquisition techniques. This will include identification of data bases or sets that appear to be common to a wide variety of uses and that therefore must be used with many different companion data sets.

March 15, 1986

CRITICAL ISSUES IN NASA INFORMATION SYSTEMS

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I. BACKGROUND

Charge to the Committee. This report covers a brief study requested by the Associate Administrator for Space Science and Applications, National Aeronautics and Space Administration (NASA). The original charge to the Committee on NASA Information Systems is contained in the Statement of Task on page vi of this report. The following sentence from that Statement summarizes the basic assignment of the Committee:

> The Committee's initial task will be to identify critical issues on which NASA must act to ensure that its information systems activities lead to interoperable systems with a minimum of standardization, while providing for adaptability and growth.*

The Associate Administrator for Space Science and Applications provided further guidance on April 2, 1986, during the Committee's inaugural meeting. From this a corollary tasking emerged, which the Committee interpreted and applied as follows:

> The Committee should look beyond the technical aspects of this study and identify the critical issues affecting how the Office of Space Science and Applications (OSSA) should organize its information systems functions and programs to support space science and applications.

Due to the relatively short time period of the study, the Committee's analysis could not be of sufficient depth to enable it to offer solutions. Thus, the objective of this report is to identify the critical issues that need to be examined in greater depth to enable OSSA to prepare its data

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* The Statement of Task, p. viii, indicates that NASA is working on a Global Resources Information Database (GRID). However, NASA representatives have indicated that the GRID and its companion program, the Global Resources Information System (GRIS), have been superseded by other NASA initiatives, such as the "pilot" data systems and the Earth Observing System (EOS) that are mentioned herein. Therefore, there is no further reference to GRID or GRIS in this report.

management organization and activities for the anticipated challenges of the future. The Committee has also suggested possible approaches to the resolution of each issue, recognizing that OSSA will have to select approaches that best support NASA's and OSSA's mission goals and objectives.

The Fundamental Issue. While attempting to fulfill its charge, the Committee often raised the question, "how important is information management to the OSSA mission?" From this prime question a host of corollary questions can be derived, such as:

-- "should the Associate Administrator devote more time (personally) to information systems management,"

-- "should the management of information systems be centralized to some greater degree," and

-- "can OSSA objectives be met through existing information management proecesses or would change be beneficial."

While it may choose to seek advice in answering such questions (and many others, OSSA must answer them itself. The prime question is considered to be the fundamental issue.

OSSA's Charter and Organization. The Committee gained an insight into, and was immensely impressed by the enormous scope of OSSA's role and responsibilities. OSSA derives its responsibilities from those assigned to NASA in the Space Act of 1958, as amended: the law that established NASA. Section 203(a) of the Act includes the following functions:

-- "Plan, direct, and conduct aeronautical and space activities;

-- "Arrange for participation by the scientific community in planning scientific measurements and observations to be made through the use of aeronautical and space vehicles, and conduct or arrange for the conduct of such measurements and observations; and

-- "Provide for the widest practicable and appropriate dissemination of information concerning its activities and results thereof."

The Act also establishes objectives such as the following: (1) expansion of human knowledge; (2) identification of benefits from aeronautical and space science technology; (3) preservation of the U.S. role in aeronautical and space science and technology; and (4) cooperation with other nations in peaceful applications of space.

The organizational structure with which NASA addresses these charges is depicted in Figure 1. At the top management levels, OSSA and the other four functional offices are headed by Associate Administrators reporting to the Administrator. Each major office has functions particular to its mission, and each manages its own information systems programs.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

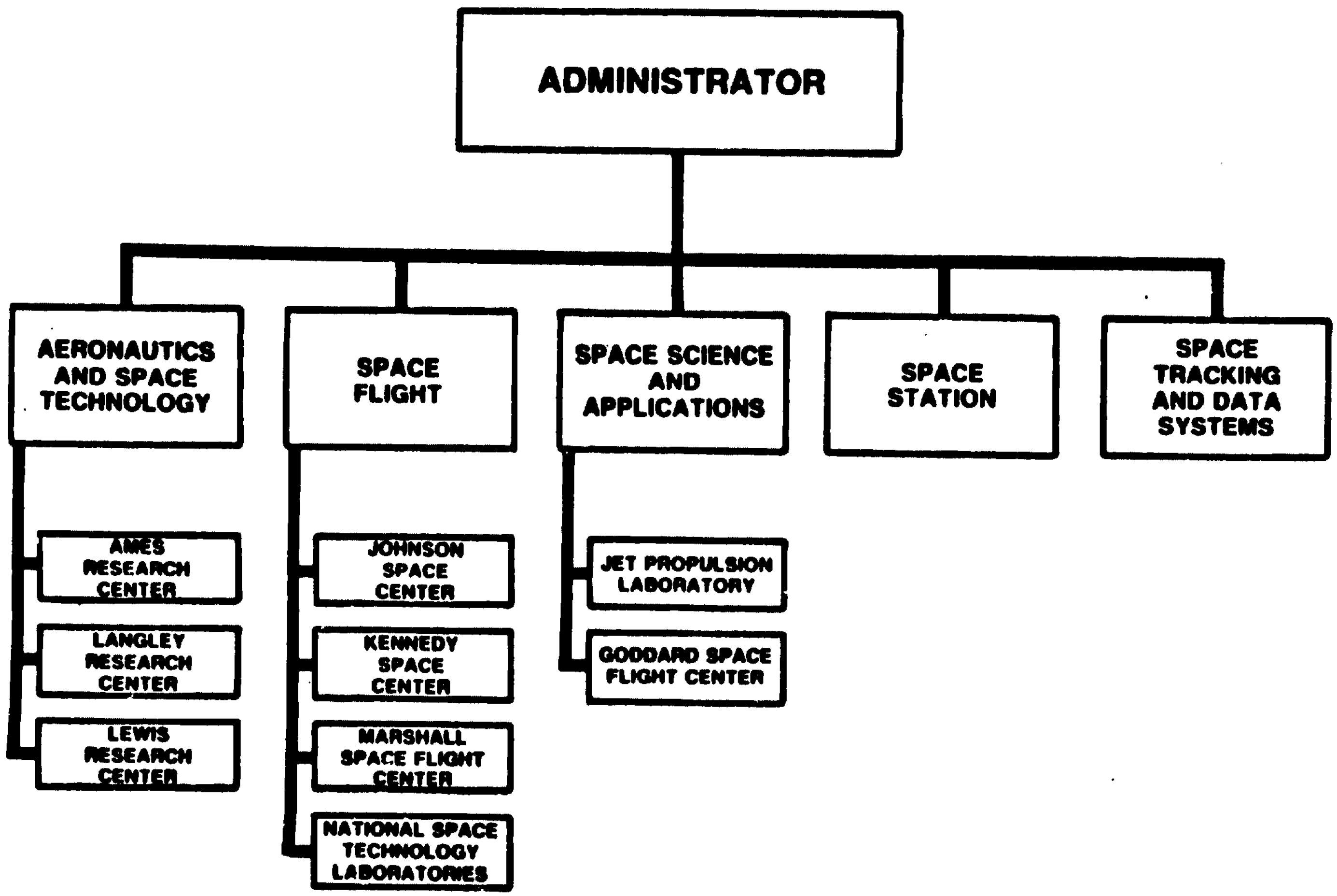

FIGURE 1

Within OSSA, the organization of which is displayed in Figure 2, there are six science discipline directorates, each reporting to the Associate Administrator, that have line authority and responsibility for the management of their discipline programs. Section III of NASA's <u>1986 Long Range Program Plan</u>, dated August 1985, describes six major programs within OSSA, summarized as follows:

1. <u>Study of the distant universe</u> attempts to answer questions about the size, scope, and structure of the universe; the origin and future of the universe; and the physical laws that govern celestial phenomena. [Office of Primary Responsibility (OPR): Astrophysics Directorate]

2. <u>Exploration of the near universe</u> is aimed at determining the origin, evolution, and present state of the solar system, and comparing Earth with the other planets. [OPR: Solar System Exploration Directorate]

3. <u>Characterization of Earth and its environment</u> is a global, interdisciplinary program, with emphasis on understanding processes that affect Earth's habitability, particularly its biological productivity and air and water quality. [OPR: Earth Sciences and Applications Directorate]

4. <u>The life sciences program</u> seeks to understand how life forms are affected by the environmental conditions encountered in space and to find out how life originated and evolved in the universe. [OPR: Life Sciences Directorate]

5. <u>The communications satellite program</u> is aimed at developing and demonstrating technology that will relieve geostationary orbit congestion and frequency allocation shortages, and permit new communications, navigation, and search and rescue services; developing and supporting national interests in the regulatory aspects of satellite communications; and developing and promoting communications satellite interconnectivity. [OPR: Communications Directorate]

6. <u>The microgravity science and applications program</u> investigates the behavior of material in a fluid state, the effects on that behavior of carrying out various processes in space, and the effects of gravity on processes carried out on Earth, and it seeks to exploit the unique characteristics of space by developing processes superior to those employed in the gravity environment of Earth. [OPR: Microgravity Science and Applications Directorate]

Prior to 1978, information management was entirely decentralized among the science directorates. Under this arrangement numerous successful missions, such as the Geostationary Operational Environmental Satellite System (GOES), were launched, and their data systems generally met the needs of their own missions at the time. However, each data system was

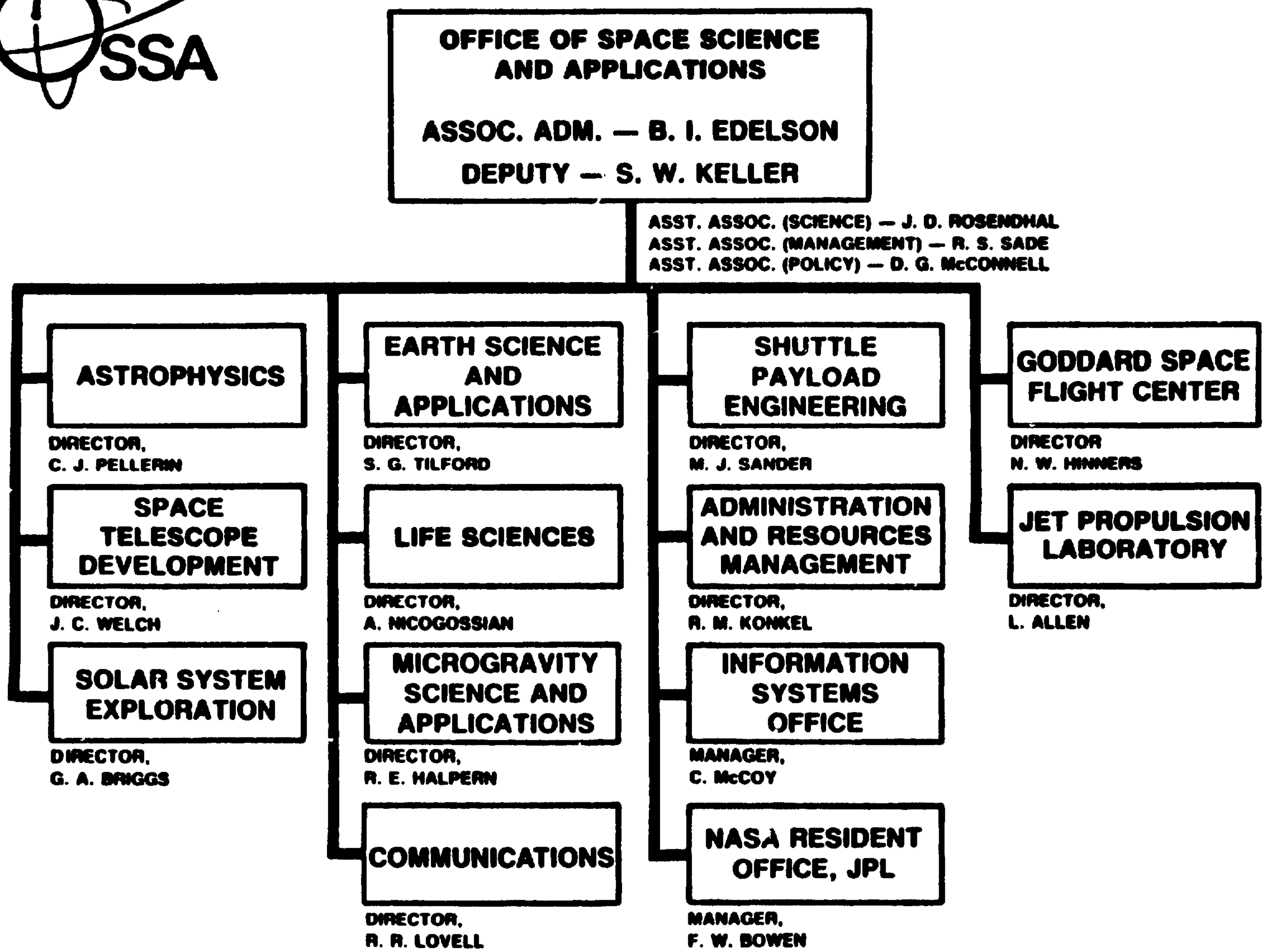
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FIGURE 2

designed uniquely for its own project, an approach that has led to incompatibility among the different systems. This has presented operating difficulties to users accessing data from several different projects' systems for their research analyses.

The science directorates still have the primary responsibility for planning and managing the information systems portions of their assigned projects, but they now receive assistance and support from the small Information Systems Office (ISO) that OSSA established in 1978. The ISO but it performs various advisory functions and a growing array of other responsibilities. The ISO provides advice to the Associate Administrator, supports the science directorates, conducts studies on information systems applications and technology, operates the NASA Space Science Data Center (NSSDC) at the Goddard Space Flight Center (GSFC), and is responsible for coordinating information systems program activities across the NASA organizational structure with offices that are involved in OSSA mission flight programs. The ISO is also involved in numerous cross-disciplinary activities and it has taken the lead in exploring technological solutions to OSSA's requirements.

The ISO has no line authority, since it was initially established to be a consulting and advisory office. In recent years, however, it has become more heavily involved in the planning and execution of information systems. For example, the ISO was given the responsibility for providing "pilot" data systems to the ocean, climate, land, and planetary exploration programs. Each pilot program is a systems-engineered testbed for applying new and evolving technologies to address the information systems needs of a discipline. When the pilot demonstrates successful improvements in data access and manipulation, it becomes operational and it is turned over to the client discipline for subsequent funding and support. At least one of the four pilot programs mentioned above, the Pilot Ocean Data System (PODS), is now considered operational. The Committee was quite impressed with the scope of the ISO's activities, considering the fact that only three professionals and two secretaries are assigned. As presently constituted, the ISO must rely heavily on support from GSFC, JPL, and various contractors to fulfill its present responsibilities.

In mid-1986 the Earth Science and Applications Directorate agreed to assign to the ISO the program management responsibility for the Earth Observing System's (EOS) information system--clearly a formidable task. The EOS Data Panel considers EOS to be essentially a very large, long-term program involving multi-disciplinary data collection, and processing, and analysis. However, unlike the data processing in most other projects, where value resides in the final product, the value in EOS is seen to be distributed over many stages of data processing, since its data are meant to serve as a dynamic resource for research on global phenomena.* This will require an information system capable of retaining all of the EOS

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* Report of the Eos Data Panel (Robert R. P. Chase, et al.), NASA Technical Memorandum 87777, Volume IIa, 1986, pp. 24-25.

data. The EOS Data Panel further indicated that the unique characteristics of EOS will necessitate the establishment of new principles for data composition, arrangement, storage, archiving, and catalog documentation.

Even when EOS is not taken into consideration, there is a great deal of integration and interaction among offices within NASA that involves the six OSSA science directorates and OSSA's ISO. Examples:

-- Each of the science directorates depends on the Space Transportation System, managed by the Office of Space Flight, to carry its satellites and other instruments aloft.

-- Each of the science directorates has planned experiments or operational activities involving the Space Station, and all NASA program offices are involved in Space Station planning.

-- Space research missions conducted by the Office of Aeronautics and Space Technology support the missions of the science directorates, and are influenced by them.

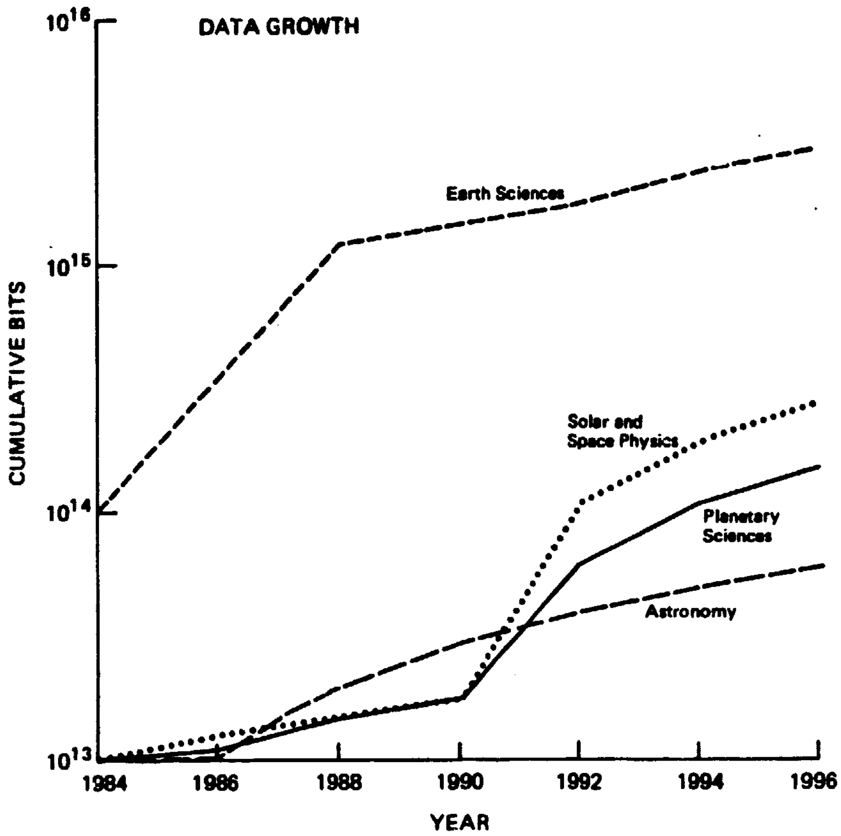
-- The Office of Space Tracking and Data Systems supports the science directorates' missions through the space and ground network that includes the Tracking and Data Relay Satellite System (TDRSS).

Quantification of OSSA's Data Management Problem. The four major issues identified by the Committee are summarized in Chapter II and a more detailed discussion of each is preseted in Chapters III through VI. Reference is made in those chapters to the large increases in data with which OSSA, its components, and its researchers will have to cope, particularly in the land, ocean, and atmospheric sciences. However, some quantification is required early on, to enable the reader to calibrate the scope of the data management problem. Figure 3 and Table 1, on the next two pages, summarize anticipated data growth and rates during the next 10 to 15 years. Further information on data volumes and rates is presented in Figures 5 through 7 and Table 2, at the end of Chapter VI.

Reference is also made throughout this report to the increasing interdependence among the various science disciplines and their component parts. This is displayed graphically for the Earth System Science disciplines in Figure 4, on page 27 (Chapter IV).

After the Committee had completed its data-gathering phase and began to draft this report, it encountered an innate tendency among its members to recommend solutions to NASA's problems as perceived by the Committee. On reflection, however, it was decided that the report should stress the identification of issues, as NASA had requested, and limit its recommendations to those that might assist NASA in determining how to approach the issues. These recommendations generally are couched in terms of suggested approaches to the issues, and thus are not accorded any particular degree of emphasis.

Projected Growth Rates for Space Science Data.



Note: Earth orbital missions assumed to last for 5 years, except for operational satellites and the space telescope, which are projected as continuing data producers.

Source: Issues and Recommendations Associated with Distributed Computation and Data Management Systems for the Space Sciences; Committee on Data Management and Computation, Space Science Board, NRC; National Academy Press, Washington, D.C.; 1987.

Figure 3

Table 1. Data Expected From a Number of Missions in the Land, Ocean, and Atmospheric Sciences

MISSION	STATUS	YEAR	DATA VOLUME EXPECTED
Geostationary Operational Environmental Satellite G, H	On-going	On-going	1.5×10^{13} bits/year
NOAA F-J	On-going	On-going	10^{13} bits/year
Earth Radiation Budget Experiment	Approved	1984	10^{12} bits/year
LANDSAT D, D'	On-going	On-going	10^{14} bits/year
Topography Experiment for Ocean Circulation	Planned	1988	10^{12} bits/year
Geopotential Research Mission	Planned	1991	10^{12} bits/year
Shuttle Imaging Radar B, C, D	B=Funded C/D=Planned	1984, TBD	6×10^{14} bits
Shuttle Imaging Spectrometer	Planned	1989	10^{13} bits
EOS	Planned	1990s	10^{12} bits/day

Note: Current volume of Landsat data is approximately 10^{14} bits, while 2×10^{13} bits of other data exist. Current volume at NSSDC is approximately 7×10^{12} bits. Similar tables are available from other discipline areas.

Source: Issues and Recommendations Associated with Distributed Computation and Data Management Systems for the Space Sciences; Committee on Data Management and Computation, Space Science Board, NRC; National Academy Press, Washington, D.C.; 1987.

II. SUMMARY OF ISSUES

<u>The Fundamental Issue: Reprise</u>. How important <u>is</u> information management to OSSA's mission? The functions and objectives listed on page 2, Chapter I, tend to imply a need for large and sophisticated data gathering, storing, and distributing capabilities. Indeed, the Committee understood that NASA and OSSA already have considerable information management capabilities, and that the requirements for considerably greater capabilities are destined to grow much larger. Even the combined impact of the Challenger disaster and the forced budget reductions stemming from the Gramm-Rudman-Hollings Act have served only to slow down the implementation of NASA's and OSSA's plans; the planning goes on.

One example is EOS. OSSA's EOS Data Panel has made the following forecast:

> "The EOS data and information system will be required to handle daily more data than any system ever conceived. In general terms, EOS will produce several orders of magnitude more data per day and is envisioned to have a duration exceeding any mission ever before proposed." ... "Clearly, the operation of an EOS data and information system will create management problems of a magnitude that cannot even be fully appreciated at this time by either NASA management or the scientific research community who must cope with these data in their research."*

The Earth System Sciences Committee of the NASA Advisory Council has emphasized the increasing interaction, interdependence, and synergism of the Earth-science disciplines,** and asserted the following:

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* <u>Report of the Eos Data Panel</u> (Robert R. P. Chase, et al.), NASA Technical Memorandum 87777, Volume IIa, 1986, p. 27.

** The Earth System Science disciplines include Atmospheric Physics and Dynamics, Marine Biogeochemistry, Ocean Dynamics, the Stratosphere and Mesosphere, Terrestrial Ecosystems, Terrestrial Surface Moisture and Energy Balance, and Tropospheric Chemistry.

"Of paramount importance to the successs of Earth System Science is an advanced information system that will promote productive use of global data. The worldwide space and in situ observations required for a deeper understanding of the Earth System can be utilized only if the research community has effective access to them. The design, development, and management of the requisite information system are tasks that approach, in scope and complexity, the design, development, and operation of space-based observing systems themselves." ... "Such an information system is clearly a formidable undertaking, but it is essential to the pursuit of Earth System Science."*

Evidence such as the foregoing tends to indicate that information management is very important to the OSSA mission and will become even more important as future science discipline programs emerge and undergo development. The Committee has heard the Chairman of the Earth System Sciences Committee and others say that the future success of NASA is tied to the development of integrated, interdisciplinary, multi-task missions. Future missions will become more complex and will depend much more on coordination and collaboration across the staff. The associated information systems will be much more complex than their present-day counterparts, which generally support single-discipline, single-task missions in support of a single staff activity and which may not be compatible with one another in software or protocols.

Introduction to Issue #1 - Centralization of Management Functions. One might then ask whether OSSA's existing information management organization and processes can handle the tasks to be faced. The Committee members felt intuitively, in the absence of definitive evidence to the contrary, that the scope of future tasks is of such magnitude that they would be beyond the capabilities of the existing organization and processes. This presumption is based on the following:

-- The authority and responsibility for information systems management is distributed among the ISO and the science directorates, with most of the authority residing in the latter; however, none of these activities is in charge of the overall effort, and the Committee believes it to be essential that someone be placed in charge.

-- The ISO in its present form is simply too small to handle by itself the workload associated with the types of future missions envisaged or to provide much in the way of leadership and direction on information systems to the science directorates.

* Earth System Science Overview: A Program for Global Change, Earth System Sciences Committee (Francis Bretherton, et al.), NASA, 1986.

There are strong indications that OSSA recognizes the problem. The recent assignment of EOS information systems management responsibility to the ISO tends to indicate an inclination within OSSA toward centralization of information management responsibilities. Indeed, the continued existence of the ISO can be interpreted to mean that some degree of centralization is favored. However, it is not clear to what extent the ISO's authority or resources will be increased through this action, or whether any such increases will be sufficient to enable that office to provide central direction of the overall future information systems planning and management workload.

Based on the foregoing, the Committee identified the following as an issue that warrants further, more detailed examination:

> <u>Issue #1</u>: To what degree should information systems management and planning be further centralized?

According to the briefings and literature the Committee received, a great deal of work is being accomplished effectively with the present organization and process. The question is not whether OSSA is doing its information systems job--because it has been--but whether its management and technological approaches can be improved to enable it to discharge the much more complex tasks demanded by such upcoming missions as EOS and the Earth System Science program. However, during the course of this study, the Committee reached certain conclusions that support the idea that OSSA ought to examine this issue closely. For example:

-- The fragmentation of information systems functions within OSSA might well impede any significant progress toward OSSA's goal of interoperable systems with a minimum of standardization, but with provisions for adaptability and growth.

-- There are numerous instances in which benefits have been realized in other government agencies and in industry through the selective application of centralized management principles. By strengthening the information systems organization through some degree of further centralization, OSSA probably could realize improvements in the following areas:

  - Strategic, long-range information systems planning.
  - The allocation of resources for internal or external acquisition of new technology and for internal or external pursuit of research and development (R&D) in information systems.
  - Shortening of procurement and acquisition cycles, to ensure timely emplacement of effective, current technology and to facilitate cost-effective life-cycles for information systems.

- Development and implementation of a cohesive plan for the creation and control of software, similar to the unified approaches taken within the commercial sector.

See Chapter III for further discussion of Issue #1.

Introduction to Issue #2 - Interoperability. NASA's successes in implementing space science and applications missions over the last two decades are well known. Most of these missions and their supporting data and information systems embodied the latest technological practices in existence at the time. Much of the data still exists and is used by the scientific community on a regular basis. However, in most cases the data remains in its original form and format, and it resides in data archives and is accessed by information systems that were developed for specialized purposes that are not compatible with systems being used today or, in some cases, with one another.

OSSA has recognized this problem and has supported activities by its ISO that move toward remedying it. OSSA's pilot data systems were designed by the ISO to have a degree of standardization and interoperability, but not necessarily among each other. The situation is not so favorable among other existing systems, and future systems are expected to have more extensive and demanding requirements. This could continue the problems of the past, in which researchers in one discipline were unable to use their data network to access the data base of another discipline.

The complexity of future systems and their supporting data and information systems makes it all the more imperative that suitable standards be selected and adopted soon. Unfortunately, there are no simple solutions and the Committee considers the following to be a second issue that should be examined in greater detail by OSSA:

Issue #2. How can interface requirements be established that would ensure interoperability with a minimum of standards?

If OSSA had but one information system, or if its information systems enjoyed a high degree of homogeneity, interconnection and interoperability would not be an issue. Unfortunately, OSSA's information systems are largely inhomogenous in their data base formats and languages, their operating systems, and the composition of their network protocols. Several aspects of the interoperability problem are being addressed by OSSA, the Office of Space Tracking and Data Systems (OSTDS), GSFC, and JPL. These include development of the NSSDC On-Line Data Catalog System (NODCS) and important work on Standard Formatted Data Units (SFDU).

An important part of the interoperability and interconnection issue is that of data transport among information systems. It has been concluded that the Department of Defense (DoD) program to establish interoperability among its networks succeeded primarily because DoD mandated the use of its Transmission Control Protocol (TCP) and Internet Protocol (IP), which were developed in the 1970s. In 1983, the International Standards Organization

("ISO"), adopted a new Transport Protocol (TP-4) as a Draft International Standard.* However, DoD TCP is not compatible with "ISO" TP-4. To give itself maximum flexibility, DoD plans to adopt its TCP/IP and the "ISO" TP-4/IP as coequal standards after a satisfactory demonstration of TP-4's suitability for use in military networks and TP-4 products are commercially available.**

During 1986 both industry and the government embarked on programs to expedite the eventual migration to TP-4, or, more accurately toward the "ISO"-sponsored Open Systems Interconnect (OSI) architecture of which TP-4 is a part. The Corporation for Open Systems (COS), which was formed in January 1986 by a group of computer and communications manufacturing companies, is establishing conformance and interoperability test programs to verify member-companies' product compliance with the "ISO" OSI standards. The purpose is to to assure acceptance of an open network architecture in world markets by accelerating the introduction of interoperable, multivendor products and services. COS presently has 61 members, including three British companies, one Italian company, and representatives of the British and Canadian governments. In early September 1986, the government announced establishment of the OSI Users Committee, whose goal is to determine an OSI standard for the government. The government also is considering a revision of its procurement policies to prohibit the purchase of commercial products that do not conform to the standard, which the committee hopes to develop during 1987. NASA and 15 other agencies belong to the committee.

Current estimates range from two to five years for the establishment of networks that are compatible with the OSI architecture. OSSA should use the time available to deal with the problems associated with its older networks and to map out its approach to the problem of interoperability for the future, including the establishment of a clear migration path to the OSI architecture.

The Committee believes OSSA is proceeding on the proper course for this issue, and we encourage them to continue to exercise caution in the move toward interoperability.

This issue is discussed in more detail in Chapter IV.

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* Since the acronyms for the International Standards Organization and OSSA's Information Systems Office are the same, "ISO" is used in this report to indicate the former and ISO is used to indicate the latter.

** See Transport Protocols for Department of Defense Data Networks, a report of the Committee on Computer-Computer Communications Protocols, Board on Telecommunications and Computer Applications, NRC, National Academy Press, Washington, D.C., February 1985.

Introduction to Issue #3 - User Involvement. As indicated earlier, it will take a massive effort to have a data system in place for systems such as the EOS in 1995. Although the scope of the overall effort cannot be determined yet, it is clear that OSSA will need to marshall virtually all of its information systems resources to complete the task.

OSSA has a tremendous experience base available to it, especially that part embodied by the users, for the development of its information systems. The Committee believes that the fundamental purpose of OSSA's information systems is to support its users, so it is gratified to note that OSSA obviously values the viewpoints of its information systems users. An indication of this is OSSA's encouragement of the independent assessment and constructive criticism by user-oriented groups such as the Committee on Data Management and Computation (CODMAC), which was established in 1978 at OSSA's request by the Space Science Board (SSB) of the National Research Council's (NRC) Commission on Physical Sciences, Mathematics, and Resources.

While it is clear that OSSA has gotten its users involved in information systems planning and management, the Committee found that all too often OSSA involves users early in the information system design phase, but does not develop a continuing dialogue with them during the development phase.

The Committee acknowledges that it is extremely difficult to decide just how far to go in promoting user involvement in the entire information systems process. Because of this inherent difficulty, the following is considered to be an issue that requires further study:

> Issue #3. To what extent should OSSA involve its users in the development of and changes to information systems, while still maintaining control?

OSSA personnel with whom the Committee dealt acknowledged the need to involve users in defining the limits of its data systems. It makes no sense to field a data system if reasonable use of its output has not been pre-determined. The Committee notes that some of the existing Pilot Data Systems provide more data than the users can absorb. Likewise, the design limits of data systems should be considered when designing spacecraft and instruments. The Committee believes that most users will participate gladly in the identification and evaluation of trade-offs between data system costs and research funding.

The Committee considers the International Solar-Terrestrial Physics program to be a good examples of iterative (and effective) user involvement in the planning. Conversely, the design of the high resolution imaging spectrometer (HIRIS), which is part of the EOS instrument package, is an example in which OSSA does not seem to be interacting quite so effectively with the users.

See Chapter V for further discussion of this issue.

Introduction to Issue #4 - Information Systems Technology. OSSA knows that the increasing emphasis on interdisciplinary and multidisciplinary scientific work will change the way information systems are structured. With the arrival of the Space Station era, mission and discipline boundaries will overlap, and huge volumes of data will be collected by NASA and others to support a large number of interdisciplinary projects involving hundreds of scientists. Comprehensive planning has already been initiated for such missions and for the associated data and information systems to handle the huge volumes of data and the product requirements of the users. But the Committee is concerned about the apparent trend toward development of higher data-rate instruments for use in remote sensing. There is evidence that the current digital magnetic recording and compact disk (CD) read-only memory (ROM) technologies cannot cope with anticipated data rates in the Space Station era. Further, commercial database management systems currently do not have the features required to manage large volumes of space-derived data. Therefore, the following is suggested as the final major issue to be addressed by OSSA in the context of this study:

Issue #4: How can the projected information systems technologies keep pace with future sensor outputs?

Additional areas of technological concern are: (1) the need for cohesive planning and a unified approach to the creation and control of software, and (2) the fragmented electronic communication and problems of transferring data in many incompatible formats among elements of the OSSA and the user community.

These technological problems are compounded by such management and operational considerations as the need to control costs (which potentially affects OSSA's ability to support the users) and the need to support the users (which influences costs).

This issue is discussed further in Chapter VI.

III. CENTRALIZATION OF MANAGEMENT FUNCTIONS

As indicated earlier, the Committee believes that the Office of Space Science and Applications (OSSA) recognizes the extreme importance of information management to its mission, as well as the need for considering possible changes to the way information systems are managed. Key personnel in OSSA are aware of studies indicating that the management of information systems will become much more complex in the future, as interdisciplinary and multidisciplinary missions increase in frequency and importance. A number of steps have already been taken to provide a more centralized focus on OSSA's information systems management, including the establishment and subsequent growth in responsibilities of the Information Systems Office (ISO). While the Committee and most NASA personnel with whom it met favored some further degree of centralization, no one (as yet) has determined how much more should be sought. Therefore, the Committee believes OSSA should strive to answer the following:

> Issue #1. To what degree should information systems management and planning be further centralized?

The Committee does not subscribe to the notion that if "some" is good, then "more" must be better. Overcentralization of information systems management functions could lead to serious problems; much depends on the actual functions to be centralized. The development of data systems requires an ongoing interaction between users and members of a project responsible for the mission data system. Major issues concerning scope and cost need continuous review by all those involved. Certainly, OSSA would want to avoid a management system in which systems solutions are promulgated from above without the appropriate level of user input. A proper balance is needed, to ensure the information systems function does not become a barrier between the scientists and the mission data systems people. The Committee does not know what the proper balance is, nor does it expect OSSA to be able to define it without considerable review and perhaps trial and error.

In the discussion that follows, the Committee offers, for OSSA management consideration, those observations believed to be pertinent to this management issue.

The Present Role of the ISO. The ISO is one of the functions depicted in Figure 2, Chapter I that has advisory functions but no line authority. NASA Management Instruction 8030.3A, Policy Concerning Data Obtained from Space Science Flight Investigations, identifies the ISO as responsible for establishing policies for management of space science data and for management of the NASA Space Science Data Center (NSSDC) at the Goddard Space Flight Center (GSFC). It is also responsible for coordinating information systems program activities across the NASA organizational structure with offices that are involved in OSSA mission flight programs. Several years ago it was assigned the responsibility for providing the pilot data systems mentioned earlier, and more recently it was assigned management responsibilities for information systems in support of the Earth Observing System (EOS) program. However, the bulk of program funding authority and responsibility for information systems rests with the program management offices for the particular disciplines. The ISO exercises little influence over the activities of these program offices and is neither authorized nor equipped to carry out the management obligations necessary to the success of the integrated earth sciences information systems program. The ISO can advise the program offices on development of their information systems but it has no authority to invoke common design features that could result in economies of scale or commonality of characteristics across different mission programs. Nor can it exercise line authority to ensure use of the latest technologies in flight-mission ground information systems, even if those technologies are proven and could produce greater efficiency of processing at lower cost. More than half of the ISO annual budget is devoted to management and operation of the NSSDC, with the balance spread over a variety of studies and consulting bodies. Little time is put into the actual management of information systems, nor can it be with the ISO's small staff. It is difficult to imagine how the ISO could accept the assignment of additional responsibilities or greater authority without a concomitant increase in personnel and financial resources.

Philosophical Focus. Traditionally, information has been considered as a cost of doing business and is generally regarded as a subservient but necessary line item to be tolerated. This was largely because the databases making up these systems were diverse and originated from a variety of sources and formats, and because computer processing was required for the large quantities of raw data generated by the space platform. Digital cartographic and image database development, coupled with existing digital data sources and the computational capability to organize and manage them, has elevated information systems from a disparate aggregate of independent data to a highly organized, independent resource that can stand on its own as a management function. Recognizing information as a manageable resource in its own right is a philosophical step necessary to establish a favorable climate for any structural changes that might be required. At the field centers the Committee has seen an awareness of the need for such management development. The EOS project office at the GSFC has indicated recognition of some aspects of this, and at the Jet Propulsion Laboratory (JPL) a set of standard performance requirements for science information systems has been promulgated. But OSSA has not, thus far, provided an organized thrust that might bring a unified management focus to science information systems, ensuring commonality of design approaches sufficient to achieve the objectives of integration (interoperability) across the scientific discipline projects and programs within the OSSA.

The Need for a NASA Information Systems Focal Point. NASA, the National Oceanographic and Atmospheric Administration (NOAA), and the National Science Foundation (NSF) are jointly engaged with the international community in a program of integrated earth systems science to enhance understanding of how the component parts of the Earth system function, interact, and may be expected to evolve. Understanding depends on the development of information, which in turn depends on the gathering and processing of data that, in the context of integrated earth systems science, is increasingly interdisciplinary. Although these joint activities are being conducted as shared responsibilities among the participating agencies, the watchwords are "integration" and "interoperability." Within each participating agency, as well as across agencies, the information systems of the component scientific disciplines must be able to cope not only with rapidly increasing requirements for storage of and access to data, but also with problems of compatibility or interoperability among diverse data bases and information processing systems. NASA's very successful experience over the years in working with NOAA on the weather and climate program could well be used as a model by OSSA to establish sound, continuing interagency relationships in its (multidisciplinary) information systems programs. We understand that memoranda of understanding with other agencies are already in preparation, and are pleased to see this initiative toward good, interagency working relationships in information systems. The Committee believes it is critical to the success of the program that, within each agency, top-level management authority and responsibility be established for that agency's integrated (earth science) information systems, and that the agency manage those integrated information systems as comprising a program in its own right. This suggests that each agency will need to have a strong, ably staffed, and adequately funded program office to manage the information systems program as a service or resource to the mission offices, responsive to their requirements. In this context, the logical choice for the NASA focal point would be the OSSA focal point for information systems management.

Structural Focus. A common approach to secure management control over a particular set of functional activities is to focus on organizational structures. In this instance, the goal would be to establish a structure that would facilitate the changes needed to achieve interoperability or compatibility among OSSA's discipline and mission information systems. The approach favored by a majority of committee members is establishment of a program organization for information systems. That is, placing the information systems management function at a senior management level coequal with the program Directors, with line responsibilities and budget authority derived in part from them and in part independent. If such an approach were to be taken, a statement of commitment will have been made as to the relative importance of information resources within the organization, and at a level understood by all. This might also tend to insulate the activity from interdepartmental mergers such as have been proposed from time to time, and which would tend to dilute the function of this organization, if not render it ineffective. A strong, semi-independent, information systems office could provide the information resource focal point having management responsibility for:

-- System engineering plans, including studies to achieve optimum compatibility or interoperability among information systems, and systems that meet the needs of OSSA's science mission;

-- A work breakdown structure showing the interfaces needed to achieve the requisite compatibility or interoperability among the various information systems;

-- A milestone schedule for achievement of that compatibility or interoperability across the designated interfaces;

-- An integrated test bed for simulation, modeling, and early design and prototype testing to accelerate procurement and acquisition cycles and to prove out performance; and

-- A research and development (R&D) plan to ensure, with operation of the test bed, that fielded systems evolve with state-of-the-art technologies to meet projected needs.

The Committee doubts that any existing program or project office can do this. Nor does there appear to be a single NASA focal point that attempts to integrate information systems programs while addressing a work breakdown structure approach to the issue of interoperability.

Long-Range Planning for Information Systems Activities. An important question related to the centralization issue is that of planning. That is, how can the planning best be managed, and who can best manage it? The long-range planning activity involves establishing a realistic planning horizon commensurate with organizational and functional mandates (usually 5-10 years, depending on the systems being supported). Management's perception of the organization at the end of the planning period, set against the current situation, provides the framework for goal-setting and objective statements, but this is not enough. Action plans to achieve the goals and objectives, and to identify tasks, schedules, benchmarks, milestones, resources required, and comparative costs will expose the goals and objectives to the realities of practical accomplishment. The Committee suggests that program plans be developed to address four areas:

-- The design and development of future space program data and information systems to provide the level and degree of interoperability required by multi-discipline investigations;

-- Transformation and integration of OSSA's present data and information systems to support an acceptable level of interoperability;

-- Determining what reformatting or further documentation and archiving of existing historical scientific data and information is required to support future multi-discipline investigations; and

-- Transformation of the separate networks into a common OSSA network.

Perhaps a logical place to start would be the pilot and EOS programs, for which general goals already have been established. A capability to measure progress could be provided by defining an action plan that identifies intermediate milestones and the schedule for each program or project. To monitor actual performance, formal periodic reviews should be held to assess the status of the program or projects as related to the plan. These reviews would also serve as a feedback mechanism to redefine requirements, assess responses to pre-defined user requirements, and identify the need for future special projects or systems research requirements.

A hiatus of two or more years in NASA launches presents both problems and opportunities for OSSA data and information systems planning. The most recent announcement puts the next shuttle launch in 1988. It is unlikely that NASA will have an expendable launch vehicle (ELV) ready before that time. During at least the first year of resumed shuttle operations the Department of Defense (DoD) will have priority on payload space. Therefore, the earliest possible new OSSA sensor will not operate for at least two years, and most of the planned instruments are not likely to be in orbit until between two and six years from now. During the hiatus the ongoing OSSA programs will have data available only from existing databases and existing, orbiting, U.S. and foreign sensors. This presents an opportunity not only to enhance the utility of existing information systems, which certainly should be done, but also to use the potential networking of existing U.S. and foreign systems as a building block for future EOS information. Further, there is time available to plan, design, and implement information systems that will be required for future sensor suites.

Information Systems Research and Development (R&D). Another logical question to be addressed when considering centralized management is: does OSSA need an information systems R&D focal point? A mature management structure typically allocates a portion of its resources to R&D. OSSA has three options available for R&D: perform it in-house, obtain support from other NASA activities, and obtain support from outside NASA. The relationship between the NASA's Office of Aeronautics and Space Technology (OAST) and OSSA is one in which the basic technology development is conducted by OAST and then transferred to OSSA for application in flight missions. This relationship ostensibly applies to the information systems function as well as others, but it is not apparent that the necessary programmatic coordination to effect that transfer is taking place. Currently, the Office of Space Tracking and Data Systems (OSTDS) addresses space-based data systems and software engineering methodologies but has no active program in ground-based data and information systems technology. In its current ground data and information systems function, OSSA evaluates prototypes of commercially developed technologies but does not identify and carry out any advanced technology developments on its own. Clearly, there is an interest in OSSA R&D that should be considered, especially in the area of information management systems. Evaluation, follow-up and procurement from the commercial marketplace may be more appropriate in some cases and become more important as commercial development of these systems expands.

Management of Information Systems "Build-or-Buy" Decisions. A related question is: how can OSSA best decide whether to build its own information systems or to buy them? Decisions dealing with all elements of technology are needed from time to time on whether to build or buy. Someone has to develop and clearly articulate criteria to facilitate "build-or-buy" decisions in information systems technologies, or, in the case of a "buy" decision, criteria dealing with vendor selection. The Committee believes that much "technology rediscovery" and its concomitant additional costs can be avoided through the judicious use of vendors and value-added service companies. Requiring data users to bid competitively for data services would permit use of commercially-available technology more efficiently and at its lowest cost. It would also highlight to the user the question of data services and cost, the impact of such costs on resources available for other aspects of the investigation, and the trade-off decisions to be made. In light of the present Administration's stated policy of maximizing privatization and commercialization, this question deserves immediate focus.

Procurement, Acquisition, and Evaluation of Information Systems. Once the decision has been made to buy rather than to build, another question arises that certainly would involve the information systems manager or managers: can OSSA inprove its procurement and acquisition cycles and the timeliness of its testing to ensure effective and current technology and more timely and cost-effective life-cycles for its information systems? Many sensor platforms and information systems are being developed independently to satisfy the needs of the science community. Many of these systems are developed on a project-by-project basis. Others are integrated into a program with projects as components, such as the EOS program. Independently developed pilot or testbed systems support some of the project activities. Such independent systems need special attention to integrate them into the projects they support. The effort required can be reduced through the use of two techniques widely used in industry to shorten procurement and acquisition times--rapid prototyping and integrated testbeds.

Rapid prototyping involves simulation and modeling techniques for establishing operational concepts and performance characteristics of proposed systems and for validating them before the systems are designed and built. Rapid prototyping can be done in software laboratories. It does not necessarily require large, integrated testbeds to arrive at system procurement specifications, but it should include user participation through simulation and modeling of user interfaces with the proposed system models. Its technology involves three elements: (1) processes to understand users' cognition and work styles, determine tasks and work scenarios, and define driving functions of the system design; (2) a set of (software) tools for rapid building of prototype simulation models for iteration with users; and (3) a reconfigurable (software) laboratory for prototyping and user validation. The primary focus of rapid prototyping is a dramatic reduction in the risk of building user-interactive systems with radically shortened procurement and acquisition times through iterative simulation, modeling, and verification processes.

The integrated testbed is a collection of some real prototype elements of a proposed or developing system together with simulations of remaining elements, that exhibits characteristics of the intended operational system. Some thought would be required to define how major projects such as EOS could be supported with an integrated testbed. Consideration might also be given to an OSSA space sciences integrated testbed, to provide a comprehensive capability to demonstrate and evaluate archectectures and key technologies in accordance with an overall program plan. The integrated testbed might encompass additional rapid prototyping capabilities, simulations, and models with a hierarchy of fidelities to address the specific program at hand; hardware and software in the loop; and testing capabilities necessary to validate requirements, system elements, simulations, and models. With such capabilities, the testbed could be used to: (1) simulate the overall architecture; (2) support full-scale development decisions; (3) identify technology drivers; (4) identify crunch points; (5) measure the added value of new components, component changes, and technology insertion; (6) pinpoint software re-use elements; and (7) evaluate mission management schemes.

Since many pilot/testbed programs are in existence, one could consider a federated approach for existing programs, while building a model testbed program around EOS. Such an integrated testbed could also support rapid development of a prototype for users' evaluation, using the required performance to shorten the procurement cycle and enhance the opportunity to use and insert state-of-the-art technology. But the Committee emphasizes that much rapid prototyping can also be done early in concept and systems definition activities, prior to the acquisition of the integrated testbed. A similar approach has been taken by the DoD's Strategic Defense Initiative Office. Additional thoughts on procurement and acquisition approaches are provided in the next chapter.

Development of Information Systems Software. A final question that might influence decisions related to the further centralization of information systems management function is: how can OSSA best manage a unified approach to the creation and control of its software? The information systems that NASA/OSSA needs to develop to meet the requirements of the Space Station and EOS will require the development of software on a much larger scale than is being undertaken currently. In order to meet this challenge, OSSA may want to consider implementing a software development plan that includes rapid-prototyping capabilities.

The information systems that will support the Space Station and EOS will have long lifetimes, and they must improve and evolve in compatible ways over the long lifetimes of the Space Station and the EOS space platform. In addition, new projects and procedures must be installed in a smooth, compatible fashion. There has been substantial pragmatic progress made in software development technology as well as in modular language and operating-system structures. The Committee suggests that OSSA collaborate with the commercial sector on the evaluation of available technologies and the integration of these technologies into the OSSA software creation and control mechanisms.

Rapid-prototyping approaches to software development warrant further investigation to determine their applicability to OSSA. Whereas rapid prototyping of hardware systems is well understood and is becoming a widely adopted concept in the high-technology industries, rapid prototyping of software systems is a complex undertaking that does not have a broad base of experience. However, concepts and methodologies for rapid prototyping of software systems are beginning to emerge and OSSA may find it useful to develop a plan for monitoring and applying these concepts.

IV. INTEROPERABILITY

It was noted earlier that researchers in one discipline sometimes have been unable to use their data network to access the data base of another discipline. The Committee believes that OSSA recognizes this problem and wants to ensure that future systems are compatible, at least to the extent necessary to achieve the required degree of interoperability.

The present-day interoperability problems will pale in significance when compared to those of the future, especially with respect to the earth system sciences. According to OSSA's Earth Observing System (EOS) Data Panel, EOS will produce several orders of magnitude more data per day than any previous mission.* That group also reported the following:

> "On the scientific level, we anticipate system resource conflicts arising that will demand resolution within the confines of the data and information system. Multidisciplinary researchers and research teams will have needs for particular observational sequences, while disciplinary researchers may well have requirements for entirely different measurements. Both groups will be affected by spectacular events and the pressures (both scientific and political) to respond."**

An Earth System Sciences Conceptual Model. One can see the complexity of the information flows within the Earth system sciences environment by reviewing the conceptual model prepared by NASA's Earth System Sciences Committee, shown in Figure 4.*** That committee notes that changes to our planet during the time span of human history have been modest when compared to those that have occurred over geological timescales. However,

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* See page 8, citation from Report of the EOS Data Panel.

** Report of the EOS Data Panel, NASA Technical Memorandum 87777, Volume IIa, 1986, p. 26.

*** Earth System Science Overview: A Program for Global Change, Earth System Sciences Committee (Francis Bretherton, et al.), NASA, May 1986, pp. 24-25.

human activity over the next century or two may contribute to global changes comparable to those of geological history.

The major components, shown as boxes in Figure 4, should be conceived of as groups of computer subroutines incorporating detailed knowledge of the relevant processes provided by the traditional Earth-science disciplines. The pathways (arrows) that connect these subsystems represent the information flow necessary to describe the interactions among them. The ovals and the attached arrows denote inputs from, or outputs to, an external environment.

The use of models will help scientists to understand better the multiplicity of interactions among the Earth System components and to aid in predicting the future evolution of the system in response to selected changes in input variables. The model also illustrates the emphasis being placed on an integrated view of the interactions of the lithosphere; the physical climate system, including the atmosphere, oceans, and land surfaces; and the biosphere, coupled to the other components through the biogeochemical cycles. This integrated view is a fundamental aspect of Earth System Science and tends to indicate a continuing and increasing need for cross-discipline and multi-discipline data flows.

In both solar terrestrial physics and planetary science, the science requirements for missions planned for the 1990s will be different from those in the past two decades. By 1989 spacecraft will have visited two comets and all of the planets of the solar system except Pluto. The first missions were primarily missions of discovery while the missions in the 1990s will concentrate on increasing understanding. Missions are planned to Venus, Mars, Jupiter, a comet and an asteroid. The scientific problems in planetary science will require the talents of experts in a variety of disciplines. For instance, one of the most intriguing features of the Jovian system is Io and its interactions with corotating Jovian plasma, which is of Ioan origin. An understanding of the phenomena associated with these interactions requires the expertise of planetary geologists, atmospheric scientists, and plasma physicists. In solar terrestrial physics, the emphasis will be on understanding the flow of energy and momentum through the coupled systems of the solar wind, the magnetosphere and the ionosphere. This will require coordinated multi-spacecraft, multi-instrument and ground observations. In astronomy and astrophysics the 1990s will begin an era of observatories in space. Late in this decade the Hubble Space Telecope will be launched. The Hubble Telescope plus the Space Telescope Science Institute will constitute an observatory like those on earth, only with the telescope above the atmosphere.

These changes and others indicate that OSSA faces a significant challenge in the development of interoperable information systems to support forthcoming interdisciplinary and multidisciplinary missions. There are no simple solutions; the issue is:

Issue #2. How can interface requirements be established that would ensure interoperability with a minimum of standards?

FLUID AND BIOLOGICAL EARTH PROCESSES:

Detailed Information Flow

[$\phi(\ldots)$ = flux, $n(\ldots)$ = concentration]

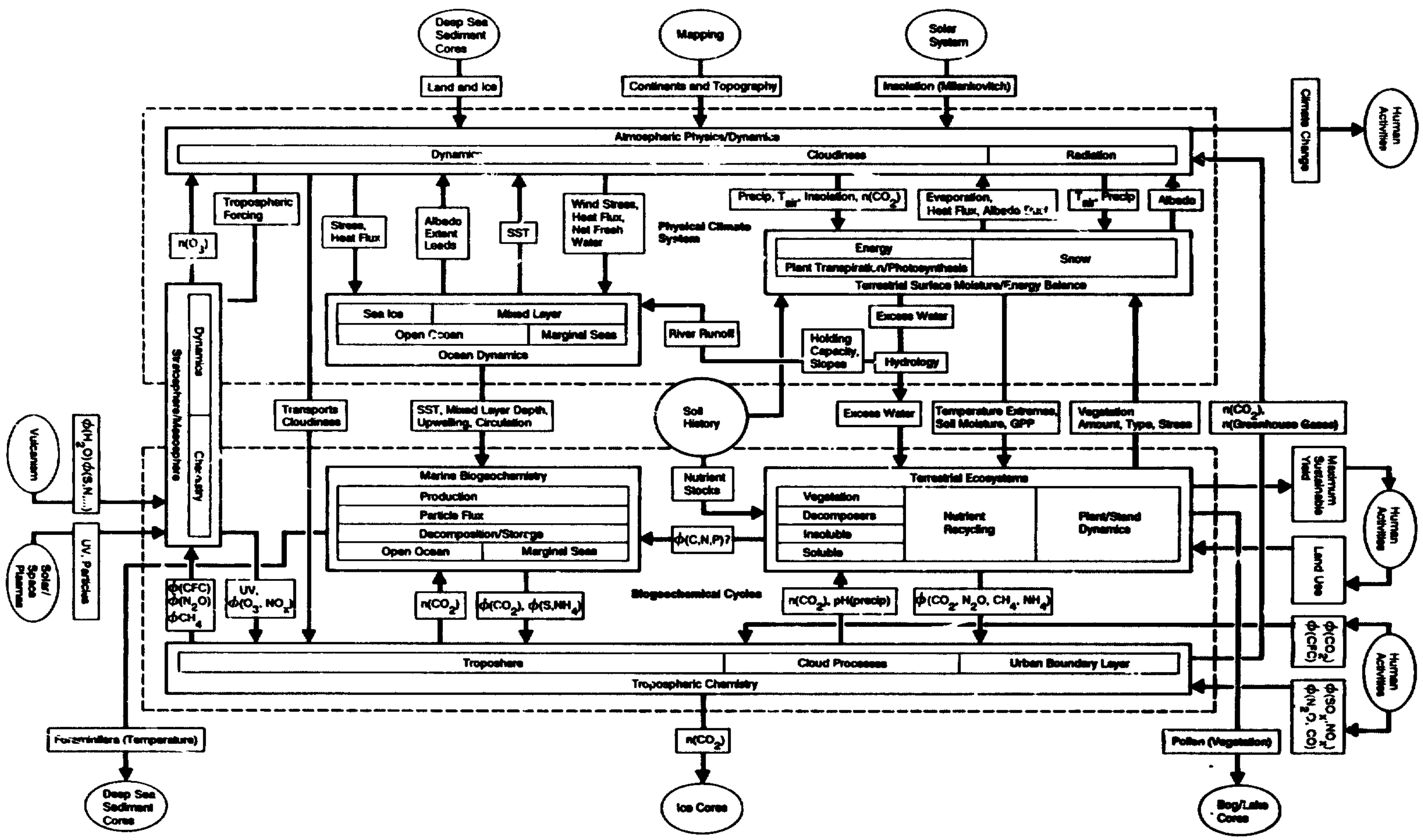

Figure 4

Interconnection and Interoperability of Information Systems. Certainly the easiest way to achieve interoperability is to have one system with identical or compatible hardware and software throughout. Practically, though, there are many reasons for keeping information systems separate, such as the need to keep old but relatively cheap systems in operation rather than lose the data or have to move it to another system. Therefore, there will always be a number of systems supporting OSSA's missions, and it appears there will be an increasing requirement for interoperability among a number of these systems. OSSA already knows that ease in achieving interoperability will depend directly on the degree of homogeneity of its systems: the more alike they are the easier it is to interconnect them. Unfortunately, OSSA information systems differ substantially in their data base formats and languages, their operating systems, and the composition of their network protocols. OSSA, in concert with the Office of Space Tracking and Data Systems (OSTDS), GSFC, and JPL, has been addressing several aspects of the interoperability problem. Examples:

-- On-Line Catalog Activities. The trend toward decentralized and distributed data bases is causing increasing difficulty for users who need information about the data bases or data from them. The NSSDC On-Line Data Catalog System (NODCS), consisting of the Central On-Line Data Directory (CODD) and the Distributed Data Catalog System (DDCS), is being developed to alleviate these problems. Once a user has decided to access a particular catalog in the DDCS, it will in some cases be possible to gain access automatically through CODD. In other cases, it will be necessary to follow procedures that CODD will provide. However, there is no mechanism planned to allow a user in any catalog to gain direct access to data in any other catalog within the DDCS, since the interface languages and data query systems differ and the systems are structured to be top-down and menu driven. The Committee felt this was a useful first step, but that further efforts are needed, perhaps through the provision of gateways, to ensure interoperability across the ocean, land, climate, and planetary data systems and perhaps among other science data systems and older meteorological and earth-observation systems.

-- Data Interchange. Both OSSA and OSTDS have strong interests in (and have been heavily involved in) the development of Standard Formatted Data Units (SFDU) as a means of facilitating both data transfer and interoperability among data systems. Most data formats now are mission-specific, but NASA wants a transition to generic structures and processes, since the goals are to maintain the data sets and relevant information in a consistent form and to enable users to obtain data with no manual intervention. OSTDS and GSFC have represented NASA on the Consultative Committee on Space Data Systems (CCSDS), a standards body that concentrates on standards for interface protocols including the SFDU. JPL also has done quite a lot of work in this area, including the development of standards that are consistent with the CCSDS recommendations regarding the SFDU. JPL's Planetary Data System will serve as the SFDU test bed for the planetary community. JPL also plans to require the use of the SFDU in other missions.

Since the less two interconnected systems are alike the more they will need conversions across the various layers of the information systems architecture, OSSA must concentrate on eliminating differences among its systems. It will not be possible for OSSA to change its older systems, so the problem is not going to go away for many years. However, the planning must begin now.

The Department of Defense (DoD) Experience with Transport P[illegible]ls. It is useful to consider the experience of the DoD, which er[illegible] similar problem in the 1970s, a period that saw the evolut[illegible] of new networks, using many different protocols. The DoD's [illegible] Research Project Agency (ARPA) established a network--ARPA [illegible] the early 1970s to serve as a research vehicle and testbed for [illegible] communications protocols. In 1978 the agency concluded fou[illegible] developmental testing on a Transmission Control Protocol (TCP, [illegible] Internet Protocol (IP), which subsequently were mandated for use as standards throughout the DoD. It has been concluded that the momentum for the DoD program to establish interoperability among its networks resulted primarily from the directed use of TCP/IP.

In the early 1980s, the National Bureau of Standards (NBS), in cooperation with the DoD, industry, and the International Standards Organization ("ISO"), developed a new Transport Protocol (TP-4) and a new Internetwork Protocol.* While DoD's TCP and IP have proven to be highly effective, and IP and the "ISO" Internetwork Protocol can easily be made compatible, TCP is not compatible with TP-4. TP-4 and the Internetwork Protocol were approved by the "ISO" as Draft International Standards in 1983 and 1984, respectively. Since commercial vendors normally consider Draft International Standards to be ready for implementation, there has been some expectation that commercial equipment manufacturers will employ the "ISO" standard protocols. If this were to prove true, organizations that employ other standards would find it difficult to find commercially-available, off-the-shelf hardware for their networks. However, industry has not produced TP-4 products as rapidly as had been expected. As a result, DoD has indicated that it will adopt TCP/IP and TP-4/"ISO" IP as coequal standards after a satisfactory demonstration of the latter's suitability for use in military networks. A final commitment will be deferred until the demonstration has been evaluated and TP-4 products are commercially available.**

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* In this report, "ISO" represents the International Standards Organization and ISO represents the OSSA's Information Systems Office.

** See Transport Protocols for Department of Defense Data Networks, a report of the Committee on Computer-Computer Communications Protocols, Board on Telecommunications and Computer Applications, NRC, National
[Continued on p. 30]

This approach will provide maximum flexibility for the DoD, by enabling it to determine whether to convert to TP-4 or to remain with TCP, depending on which standard proves to be the popular choice among equipment manufacturers. In either case, the DoD will obtain the benefits of standard commercial products at an early date. Once commercial products are available, development, procurement, and support costs should be lower. The main points illustrated by the DoD experience are: (1) adherence to some standard is necessary to achieve (inter alia) interoperability; and (2) the decision to adopt or not adopt protocols that have been promoted by national and international voluntary standards organizations can be driven as much by factors such as product availability as by the goal of interoperability.

Open Systems Interconnection (OSI) Architecture. It should be noted that TP-4 is part of a broader scheme called the OSI Architecture. The "ISO" began developing this architecture in the late 1970s, at the same time the International Telegraph and Telephone Consultative Committee (CCITT) began to develop its own OSI reference model. By 1984 the CCITT had adopted the same language as the "ISO", and the reference model now is known as International Standard ISO 7498 and CCITT Recommendation X.200.

As an indication of the seriousness with which the OSI architecture is being regarded throughout government and industry, OSSA should consider the following recent events, which also tend to indicate that OSSA might wish to orient its thinking toward eventual migration to TP-4.

-- Establishment of the Corporation for Open Systems (COS). In early January 1986, a group of computer and communications manufacturing companies incorporated COS in the Commonwealth of Virginia as a nonstock, not-for-profit membership corporation. The purpose of COS is: "to provide an international vehicle for accelerating the introduction of interoperable, multivendor products and services operating under agreed-to OSI, Itegrated Services Digital Network (ISDN) and related international standards to assure acceptance of an open network architecture in world markets." COS proposes to achieve its objectives through establishment of conformance and interoperability test programs to verify member-companies' product compliance with the "ISO" OSI standards and by identifying areas

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[Continued from p.29]
Academy Press, Washington, D.C., February 1985. The report notes that the services provided by TCP and TP-4 are functionally quite similary. but that some functions are provided in significantly different ways by the two protocols. This includes data transfer interface, flow control, connection establishment binding, and out-of-band signals. It was estimated that an experienced programmer would require about six months to design, implement, and test modifications of the three major, higher-level, DoD protocols (file transfer, mail, and Telnet) to work with TP-4.

in which standards development needs to be accelerated. By early 1987, COS membership comprised 61 computer hardware, communications, and software companies; computer and communications services providers, computer and communications users, and companies involved in the development of underlying technologies. The total includes three British companies, one Italian company, and agencies of the British and Canadian governments.*

-- Establishment of the Government OSI Users Committee. In early September 1986, the government announced establishment of the OSI Users Committee, whose goal is to determine an OSI standard for the government. The government also is considering a revision of its procurement policies to prohibit the purchase of commercial products that do not conform to the standard, which the committee hopes to develop during 1987. Fifteen agencies, including NASA, belong to the committee.**

Considering these recent developments, it would appear that OSSA's future strategy has been set, but that it still needs to concern itself with the "tactical" problems of dealing with its older networks and, for those networks that require interoperability, the establishment of a clear migration path to the OSI architecture.

The following factors (and perhaps others) need to be examined, in order to develop criteria against which OSSA can identify and evaluate suitable options:

-- functional and operational specifications (that is, will the protocol designs meet OSSA's present and future operational needs?);

-- interoperability requirements (for example, must OSSA networks be interoperable at the applications level as well as at the network access level?);

-- minimum procurement, development, and support costs; and

-- ease of transition (migration) to new protocols.

As with the issue of centralization, the Committee believes that OSSA is justified in taking a rather cautious approach to the interoperability

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* Information supplied by COS, January 1987.

** The other 14 members of the Government OSI Users Committee are the Departments of Agriculture, Commerce, Defense, Energy, Health and Human Services, Housing and Urban Development, Interior, Justice, Labor, Transportation, and Treasury; the Environmental Protection Agency, the General Services Administration, and the Office of Management and Budget.

issue. While it is clear that cross-discipline data accessibility will be increasingly important in earth-oriented discipline programs, it is not so clear that this will be the case for programs in space physics, solar physics, astronomy and astrophysics, and planetary science. It is important to determine as soon as feasible which of the disciplines require or can benefit from coordinated or common data systems and which do not require coordination. To force commonality where it is not needed runs the serious risk of increasing costs and hampering the scientific work. Resolving these questions requires working with the discipline program managers and scientists.

For those new networks that will require interoperability, it would appear the proper approach would be to focus attention on non-proprietary standards that are in place and emerging for high-speed data networks. There is no evident need for OSSA to develop new standards or technologies, but it needs to develop a strategy for the adoption of standards so that its future networks will be compatible with those of the agencies with which it will need to interoperate, such as the DoD, the National Oceanographic and Admospheric Administration (NOAA), the National Science Foundation (NSF), the Department of Energy (DOE), and other agencies with evolving networks.

The Committee understands that OSSA is considering use of the NSFnet for data as well as electronic mail distribution to researchers. Within the time-frame currently being assumed for the NASA environment, there is a reasonable expectation that the evolving NSFNet will be able to support the data rates implied by the 1- and 10-Mbps rates discussed above. The current short-term plans call for networking technology based on T1 carrier facilities (1.544 Mbps) and internet protocol (IP) routers--the switches of the NSFNet backbone--capable of 1,200 maximum-length packets per second. The limitations of current networking are not in the transmission facilities, which can go to one gigabit per second (Gbps) rates, but in the switches, gateways, and packet handlers. The development of these units to support fiber speeds is happening slowly.

However, the foregoing assumes that the information that flows onto the NSFNet is created by networks that support the NSFNet protocol family -- namely DoD's TCP/IP, evolving to the "ISO" TP-4, which has also been recommended by the CCITT. Many of the constituent NASA networks, such as the Space Physics Applications Network (SPAN), do not conform to these standards. This creates a variety of problems. The most critical is the inability of researchers to reach across from, say, the ocean data networks to the Earth science databases. Also, the lack of clearly defined standards in electronic mail, file transfer, etc., which is common across the OSSA discipline networks, makes it difficult, if not impossible, for researchers to communicate with each other. In addition the application-level gateways required would severely restrict the network throughput across such incompatible networks. Keeping in mind the approach being taken by the NSF, the DoD, and other agencies that have elected to stay with TCP/IP but eventually to migrate to TP-4, OSSA might want to consider a similar strategy in future information systems acquisitions.

Based on presentations on procurement made to the Committee, the information systems procurement process appears to be one that follows the sequence in which designs and design specifications are developed internally to a fairly detailed, well-coordinated level and then issued for competitive procurement. The process described by the presenters is quite lengthy, consuming from one to three years before a definitized, coordinated specification is generated. During the process, some dialogue takes place with potential contractors, but for competitive purposes many details are closely held internally within NASA. Contractors usually are given the opportunity to review and comment on the specification and statement of work. However, once the formal Request For Proposal (RFP) has been issued, contractors must respond to a "design-to-specification" requirement in a relatively short time. This approach often results in systems with technologies that are not state-of-the-art, and architectures that are not cost-effective in terms of the system life.

NASA presenters indicated that several significant NASA information system procurements have been issued or are planned to be issued using this approach. These include the Technical Management Information System, Program Support Communications Network, and Earth Observing Information System.

A Procurement Strategy to Foster Interoperability. The Committee suggests that an alternative information systems procurement strategy be considered--one that has been used successfully by NASA on many large space procurements--involving a competitive Concept Design Phase (CDP) based on performance requirements that will lead to design specifications. Some of the characteristics and benefits of this approach are the following:

-- Effort "Multiplier." It is expected that competing contractors will commit substantial resources during the CDP, which fact will permit the project to move forward further and faster than would be possible with government funding alone.

-- Enhanced Options. OSSA will be provided several design solutions, reflecting both the technological state of the art and the creativity of the competing contractors, enabling it to select system and subsystem design configurations that will do the job at the best price. This would enable OSSA to request and evaluate proposals that include provisions for a migration path to TP-4.

-- Industry Perspective. OSSA will learn the industry's perspective on system costs and alternatives.

-- Improved User Support. OSSA will obtain a better product by offering industry the opportunity to participate in its dialogue with the users on the mission to be satisfied. Included in this dialogue would be users who must access the system indirectly.

-- Faster System Development. OSSA will have the opportunity to prototype systems or elements of systems rapidly, as a step in shortening the development of design specifications (by introducing user requirements to engineering design, for example, as a step in the specification generation process).

The Committee believes that a procurement strategy and process fostering competition as early as possible in the acquisition cycle, particularly on large information system procurements, would enhance the probability of satisfying user and mission requirements in a more timely manner, within life cycle cost-effectiveness goals.

The adoption of common standards among the research networks of major agencies such as NASA allows users to have maximum flexibility with respect to access to their data, use of common campus networks and facilities, use of alternative access routes that provide flexibility, and use of nationally-supplied communications facilities. We believe OSSA is taking the proper approach to this issue. Time is the enemy now, however, and OSSA is faced with critical choices that must be made before the massive flood of data from the new NASA initiatives and the desire of researchers to access such data both increase the frustration of the users and make it difficult to convert from the status quo to state-of-the-art information systems that satisfy NASA's and the users' needs.

V. USER INVOLVEMENT

The fundamental requirement for an information system is to support user needs. The complete information system, consisting of instruments, data systems on the satellite, data downlinks, and processing on the ground, must acquire, manage, and distribute the data. It will take a massive effort to have a data system in place for systems such as the Earth Observing System (EOS) in 1995. It is difficult to scale the overall effort very well until the systems planning and component analyses are more advanced. However, it is clear that OSSA will need to apply considerable information systems resources to complete the task.

OSSA has shown over a lengthy period that it values the viewpoints of its information systems users. It was at OSSA's request, for example, that the Space Science Board (SSB) of the National Research Council's Commission on Physical Sciences, Mathematics, and Resources established the Committee on Data Management and Computation (CODMAC) in 1978. The CODMAC's continuing charge is to examine the management of existing and future data acquired from spacecraft and associated computations in the space and earth sciences, and to make recommendations for improvements from the perspective of the scientific user.

In its 1982 report,* CODMAC defined a set of principles and recommended that those principles "become the foundation for the management of scientific data." The first of the CODMAC principles reads as follows:

> "Scientific Involvement. There should be active involvement of scientists from inception to completion of space missions, projects, and programs in order to assure production of, and access to, high-quality data sets. Scientists should be involved in planning, acquisition, processing, and archiving of data. Such involvement will

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* Data Management and Computation, Volume 1: Issues and Recommendations; Committee on Data Management and Computation, Space Science Board, NRC; National Academy Press, Washington, D.C.; 1982.

maximize the science return on both science-oriented and application-oriented missions and improve the quality of applications data for application users."

In its second report,* CODMAC notes that progress had been made on the recommendations in its first report. One example is the initiation by the ISO of the pilot data systems, which directly involved the science community. However, CODMAC also noted its concern that neither NASA nor the space science community seem to be postured "to efficiently implement geographically distributed information systems..." It observed that NASA and the science community, with strong leadership from NASA, "need to work together to achieve the common goal -- to maximize the scientific return from space science data." To this end, CODMAC recommended that NASA establish a high-level advisory group, consisting of experienced data users (scientists) and experts in the relevant technologies, to advise senior NASA officials "on matters of data policy (and) computation and data management practices."

It is difficult to know just how far to go in promoting user involvement in the entire information systems process. Clearly, OSSA has a tremendous experience base, especially that part embodied by the users, for the development of its information systems. The question raised by CODMAC (and by several user-oriented members of this Committee) is whether OSSA is taking full advantage of that which is available to it. At the same time, the Committee recognizes that OSSA must maintain control over its systems and related programs, plans, operations, and management processes. Therefore, the following is considered to be an issue that requires further study:

Issue #3. To what extent should users be involved in the development of and changes to information systems, while still maintaining OSSA control?

Users of Space-Derived Science Data. According to the second CODMAC report, there are two types of users of space-derived science data:

-- Primary users are the principal investigators (PIs) who develop instrumentation, their co-investigators, and researchers and students who work directly with the PIs. The term "primary users" also applies to members of research teams who obtain data from a remote sensing instrument. The primary users, in general, receive data from their instrument directly from a mission data system.

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* Issues and Recommendations Associated with Distributed Computation and Data Management Systems for the Space Sciences; Committee on Data Management and Computation, Space Science Board, NRC; National Academy Press, Washington, D.C.; 1987.

-- Secondary users are scientists actively engaged in research in a given discipline, but who are not directly associated with a given instrument. Secondary users may or may not be directly associated with a particular mission. Secondary users usually receive data from an archive. Also:

== Primary users become secondary users when they want to use data from an instrument other than the one with which they are associated.

== Another example of secondary users is scientists associated with one spacecraft who wish to do correlative studies by using data from another spacecraft. In fact, all users of correlative data are secondary users.*

== In most cases, guest investigators are considered as secondary users.

== Most commercial users of space derived data are secondary users.

EOS Data Users. According to the EOS Data Panel, there will be at least four types of major users of that system:**

1. Instrument team members and support personnel associated with EOS instrument or mission operations centers. They will need to monitor a sampling of data continually in near-real time for quality assurance, error detection, and instrument malfunction assessment. They should have the capability to reconfigure observational sequences when malfunctions of special events occur.

2. Researchers, instrument team members, or operations-oriented personnel who need instrument-specific, near-real time, or real-time data processing, delivery, and display capabilities. Some of these, such as the National Oceanographic and Atmospheric Administration (NOAA) and the Department of Defense (DoD), may require large data volumes.

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* Correlative data are data that are processed in a standard way, are distributed to all interested scientists, and are used to interpret data from spacecraft. An example of this is ground magnetic data used for correlative studies in solarterrestrial physics.

** Report of the Eos Data Panel (Robert R. P. Chase, et al.), NASA Technical Memorandum 87777, Volume IIa, 1986, pp. v-vi.

3. Researchers who will need to interrogate directories and catalogs of EOS and other relevant data on an instrument, geographic location, and time of acquisition basis. They will need to order data, and in some cases they will request particular observational sequences from EOS instruments.

4. Other researchers also will need to interrogate EOS and non-EOS data directories and catalogs, but they are distinguished from the previous group by the need to browse EOS data visually through attributes or expert systems to find particular features, attributes, or special cases.

OSSA-User Interaction. During this study, the Committee reviewed background material and documentation pertaining to several missions planned for the 1990s involving astronomy and astrophysics, planetary sciences, solar terrestrial physics, atmospheric sciences, and land resource sciences. The Committee found that all too frequently OSSA involves users early in the information system design phase, but does not maintain a continuing dialogue with them during the development phase. There was a strong impression, even though the Committee was sure it was not intended, that OSSA tends to treat each mission as a new start for information systems development.

The International Solar-Terrestrial Physics program is a case where users have been involved in the planning in an iterative way. In that program members of the science community worked with NASA officials to design the data system at the same time the rest of the project system was designed. NASA officials kept the users informed of the constraints imposed by limited resources. They worked with the scientists to determine the trade-offs involved for the spacecraft, instruments, and data system, and the implications of these trade-offs on the science return from the missions. The result is a data system plan which meets all of the user requirements but is still very modest in scope and cost.

An example in which OSSA does not appear to be interacting effectively with the users is the design of the high resolution imaging spectrometer (HIRIS), which is part of the EOS instrument package. The users requested narrow bands and a wide selection of bands. The first report of over 50 possible bands was met with approval from the user community. Later announcements of 118 channels--and more recently of over 220 channels of data--were met with amazement. The Committee was unable to determine the basis for this planning, but perhaps it is based on other user requests. It seems likely to the Committee that earth resources scientists will ask for 5-7 channels of data at one time, with occasional requests for up to 15 or 20 channels, but it will be rare to see a request for 220 channels. The data rate of instruments will have a large impact on the information system needed to provide the data and information to the user. While the Committee believes the supporting information system should be responsive to the needs of the users, it hopes (in this example) that OSSA will not design an information delivery system based on sampling all of the 220 channels for one scene.

A number of strong arguments can be developed in support of involving the users in the planning of information systems. The Committee feels the most important of these might be to control costs by determining the limits of the data capability that is provided to the users.

There must be sufficient data capability to obtain the appropriate scientific, human-interest, and applied use of the data. This must be balanced against the need within NASA to save money where practical, so that as many valuable missions as possible can be flown. The Committee heard reports emphasizing that it does not make sense to fly a satellite if reasonable use of the data is not funded. The same is true of the data system. At some point costs exceed benefits and a limit to the data system should be defined, at least to the extent possible. Such cost-benefit analyses cannot be rigorously performed in all cases, but the exercise of working with the user community to define appropriate constraints would stand a good chance of providing the information needed for evaluation.

To help decide what level of effort is appropriate, OSSA needs to know who the users are, what uses will be made of the data, and what scale of user support is appropriate for a given data set. Some of the Pilot Data Systems provide more information than the users can absorb. Many critical research data sets are, in fact, not used by large numbers of people. For example:

-- A popular set of twice-daily, southern-hemisphere atmospheric analyses from Australia covered a 10-year period. Over a 4-year period, copies were sent by the National Center for Atmospheric Research (NCAR) to about 40 people at universities and other research laboratories. Another estimated 20 scientists used it on-line. Since the first rush of research on the data, the use has dropped off to about five requests per year, though a number of people probably are still using their data copies at home.

-- The most popular Nimbus data set was a set of two or three tapes having ozone samples covering 200 km along orbital tracks, active for several years. NASA mailed out copies of these tapes to 70 users. Many satellite data sets will be used by a few people (perhaps 1-10) during a several-year period while the main research is going on. Then the data will be relatively dormant while the science waits for periodic new ideas and new questions. For such data, it is mandatory to have data sets that are well-structured, well-documented, and in a catalog. In many cases, it is not useful to spend very much money in advance of the need to develop novel ways to display a particular data set. The data set situation is analogous to that of books in a library. Many essential documents are not used very often.

The National Climate Data Center, at Asheville, North Carolina, deals with data that has a wider interest than the above data. It receives about 50,000 requests a year, mostly for small amounts of printed data.

Most requests can be satisfied for costs of $3 to $15 each. In addition, many publications are distributed by subscription. Requests that demand significant resources are much smaller in number. Only about 1,300 requests each year are for digital data. About 4,000 tape copies are mailed each year. Sometimes these tapes go into other archives, where they are available to even more users. The first archive is then like a wholesaler. Many commercial firms now help to distribute weather data.

The Committee has seen that a given scientific data set may have only 5 to 50 users over a few years. However, the scientists who know most about these data may produce derived data sets that are easier for other people to use. Examples are sea-surface temperature, atmospheric analyses, ice concentration, and pictures. It is these products that usually will be used in interdisciplinary science. Some of the derived figures, summaries and pictures will go into thousands of copies of textbooks and popular books.

Just as the system throughput must be taken into consideration when designing the supporting information system, so should the limits of the data systems be considered in spacecraft and instrument design. Most scientists recognize the need for trade-offs between the data system costs and research funding, and they are willing to participate in the development of suitable compromises. They have a vested interest in the mission and they have considerable experience and expertise to offer. Such trade-offs and compromises are cheapest if they are worked out during the mission planning stage, rather than later.

Through its briefings from NASA officials, the Committee also learned of several initiatives within OSSA's domain to find common elements in satellite data systems, so that generic systems could be designed for use on such missions. This is eminently sensible, since it can save money and it can lead to an approach that will capitalize on past successes while avoiding the pitfalls of past failures. It appeared to the Committee that such efforts were particularly well-developed at JPL, where common agreement is reached by forming a working group of the appropriate experts from various flight projects and the JPL ISO. If OSSA can expand these initiatives to involve its information systems users without compromising schedule and cost constraints, a fairly rapid solution to this issue might evolve.

Another factor to be considered involves NASA's relationship with operational data users such as NOAA, the U.S. Geologic Survey (USGS), the U.S. Department of Agriculture (USDA), and other government agencies, as well as with commercial users of space data. These communities must also be considered when NASA develops new sensor technologies, since the resulting data and data products will ultimately become their responsibility. The agricultural industry, for example, needs data based on economic trade zones, not just county boundaries, and the petroleum industry has special interests in geologic profiles. These operational requirements need to be included with NASA's science and technology research objectives, to make certain the basic data is available from which new and more useful types of data products can be prepared.

VI. INFORMATION SYSTEMS TECHNOLOGY

Over the past quarter century, OSSA has employed a mission-oriented approach to the collection of data in support of a variety of science applications. During each mission, data were collected to meet the requirements of a small group of scientists in a particular discipline, using a data system that had been developed for that purpose. However, as noted earlier, there is an increasing need for interdisciplinary and multidisciplinary scientific work that will change the way information systems are structured. OSSA knows that as it moves into the Space Station era mission and discipline boundaries will blur, and huge volumes of data will be collected by NASA and others to support a large number of interdisciplinary projects involving hundreds of scientists. OSSA has already initiated comprehensive planning for such missions and for the challenge of information systems that can handle the huge volumes of data and the product requirements of the users.

As an example, the Committee is concerned that even with efficient data-rate management and control, the current digital magnetic recording and compact disk (CD) read-only memory (ROM) technologies cannot cope with anticipated data rates in the Space Station era. Further, commercial database management systems currently do not have the features required to manage large volumes of space-derived data. These technological problems are compounded by such management and operational considerations as the need to control costs (which potentially affects OSSA's ability to support the users) and the need to support the users (which influences costs). Therefore, the Committee suggests the following as the final major issue to be addressed by OSSA in the context of this study:

Issue #4: How can the projected information systems technologies keep pace with future sensor outputs?

After reviewing the technology requirements of NASA information systems in the Space Station era, the Committee believes the specific areas of technological concern are:

-- the trend toward development of higher data-rate instruments for use in remote Earth sensing, taking into consideration the actual user need and constraints imposed by information systems technology and costs (discussed below);

-- the ability of current digital magnetic recording and compact disk (CD) read-only memory (ROM) technologies to cope with anticipated data rates in the Space Station era in support of on-board processing, space-to-ground transmission, "level-zero" processing (that is, data that have been corrected for telemetry errors and decommutated), and the storage and retrieval of data (discussed below);

-- the ability of commercial database management systems to manage large volumes of space-derived data (discussed below);

-- the need for cohesive planning and a unified approach to the creation and control of software (discussed in Section III of this report); and

-- the fragmented and mostly incompatible data transfer and electronic communication between elements of the OSSA and the user community, which makes data and information transfer difficult (discussed in Chapter IV).

<u>The Trend Toward Development of Higher Data-Rate Instruments</u>. Scientific users will have limitations on how much data they can effectively evaluate. Most users will want data over a small test site or a sampling of the data to meet their scientific needs. The Committee does not believe information systems should be designed to provide all data acquired by the high data-rate instruments, unless there is an overwhelming scientific justification. A careful cost-to-benefit analysis should be made before designing a data system for the high-data-rate instruments.

Some data sensors have the capability of drowning data systems with so much data that costs become unreasonable and technology may not even be able to cope with the data stream. If all data is saved, one cannot afford to extract the information that is really needed. Several sensors such as the HIRIS and the synthetic aperture radar (SAR) that will be part of EOS dominate the planned data volume environment. Technology improvements should enable NASA to increase the cost effectiveness of handling new data by a factor of ten by 1995. However, it appears that data gathering may increase by much more than the technology gain unless careful plans are made for use of the high-rate sensors.

The data rates for SAR [about 300 megabits per second (Mbps)] and HIRIS (up to 900 Mbps) compare with data rates to good computer disks of 24 Mbps, and Cray supercomputer special-channel speeds of 1,000 Mbps. With data rates even a fraction of these, one must establish a mechanism to cope with questions of what sampling and data archiving make sense. The strategy should include a projection of year-1995 technology and costs, and an effort to drive data storage costs down. With lower storage costs, it is reasonable to save more data that will be used for local studies and case studies for short time periods. Table 1 and Figure 4 summarize data rates from selected instruments during the next 10 to 15 years (also see Table 2 and Figures 5 through 7 at the end of this chapter).

Another class of studies of growing importance requires processing data over a number of years. If all OSSA does is to save high-volume data for many years, it still cannot be used for such studies because it costs too much. Often data need to be sampled in several ways, such as the one-kilometer (high resolution) and four-kilometer resolution (global survey) data that is routinely supplied to NOAA.

A common satellite data rate of 100 kilobits per second (kbps) produces 3,160 x 10^9 bits per year, or 3,160 high-density tapes [6,250 bits per inch (BPI)] each year. An individual PI usually can cope with only 20 to 100 tapes per year. A data center usually charges $60 to $100 per tape copy, and then it often costs the PI even more to process it. The International Satellite Cloud Climate Programme is now sampling data from several geosynchronous-orbit satellites and one polar-orbiting satellite to reduce the archive from about 60 x 10^{12} bits per year to two archives, one of about 500 tapes (500 x 10^9 bits per year) and the other of about 100 tapes per year. The international processing unit at the Goddard Institute for Space Studies is able to process the smaller of these two archives to derive cloud statistics.

While the above data rate of 60 x 10^{12} bits per year has posed a difficult problem for long-term studies, it should be noted that the composite data rate being planned by NASA for 1995 is more than 50 times greater (see Figure 7).

In EOS, a NASA division proposed to limit the onboard system to handle aggregate instrument rates not over 20 Mbps. The limit is under debate. Other very-high-rate sensors such as SAR and HIRIS will be handled separately. The Committee thinks this NASA strategy is wise. The high data rates demand more careful attention to decide what sampling strategies and data rates make sense. The main uses for SAR are ocean wave statistics, ice coverage and location, and land resource studies. To obtain ocean waves, one needs only a small, square array of samples located 100 or 200 km apart from each other, perhaps closer together in coastal waters or near a major storm. As indicated above, it seems likely that user requests for HIRIS channels will be rather modest compared with the capability now being planned. The HIRIS instrument has similarities to instruments on Landsat and the European SPOT. Comparisons should be made with the data rates, duty cycle, archive strategies, and costs of these older systems, as part of the process of defining the data system for HIRIS.

In forming sensing requirements, it would be helpful if OSSA would provide feed-back to the users on the costs for different options in order to arrive at a good balance of costs and benefits. Also, the plans for future data rates and archives should factor in better technology. It is anticipated that there will be an increase in storage cost effectiveness and of computing capability (per-unit cost) by a factor of 10 or 15 by 1995. However, one cannot plan for 100 times more archiving by 1995--when technology is projected to be perhaps only 10 times better--without carefully evaluating costs and benefits.

Since the Committee did not have the time to study this matter in great detail it can do no more than suggest that it be given careful review. In particular, the Committee is concerned that the likely budget cuts in the foreseeable future will mean that increased funds for sophisticated, and therefore expensive, information systems will come at the expense of investigator, instrument, and spacecraft portions of the programs. When data requirements are being discussed, there will always be some good reasons for better space resolution, more samples in time, and more channels. However, users do not need the highest-resolution data all of the time. We believe that achieving a balance between data and information systems and other aspects of the programs is essential.

Limitations of Current Digital Magnetic Recording and Compact Disk (CD) Read-Only Memory (ROM) Technologies. Even with efficient data-rate management and control, the current digital magnetic recording and CD-ROM technologies cannot cope with anticipated data rates in the Space Station era. OSSA needs to examine and support, to at least a limited extent, the development of alternate storage technologies, to support high throughput rates and capacities. Hybrid analog and digital recording formats and optical video disks similar to laser-vision disks are examples of alternate technologies that can be exploited.

A careful examination of continuous-throughput data-rate requirements for high-data-rate sensors is needed to reduce data volumes to a manageable level that is both consistent with user requirements and affordable. OSSA, in conjunction with the user community, should develop techniques (including data compression and on-board data extraction techniques) to reduce the data throughput requirements to a level consistent with contemporary technologies that are commercially available or expected to be developed commercially in the near term.

In reviewing the requirements of the first three technologies listed on the preceeding page, the Committee adopted the assumption that continuous throughput requirements will vary from 10^6 to 10^9 bits per second (bps) in the 1990 time frame (see Figures 5 through 7 and Table 2 at the end of this section). The focus is on continuous rather than burst data rates, since the total cost and complexity of the information systems will to a large extent be determined by the continuous throughput requirements. For data rates up to 10^6 bps, technology currently exists for space-to-ground transmission, and for processing, storing, and distributing data electronically to most users. At this rate, data can be processed (level zero), archived using magnetic media, and distributed to users in real time using commercial transmission facilities. OSSA missions with non-imaging sensors or low-resolution imaging devices have continuous throughput rates of the order of 10^6 bps. These missions generate up to 10^{13} bits per year, and the data can be stored in about 10,000 physical storage units (PSU) such as tapes, disk packs, etc. Input/output (I/O) rates of 10^6 bps are easily available with tape and disk drives, and communications links operating at 1.544 Mbps (commonly called "T1" links or carriers, in reference to their commercial tariff designation) can be established easily at user locations for data distribution. Processing speeds of 10 million instructions per second (MIPS), or up to 100 instructions per byte of data, will be needed for level-zero processing. Such speeds are currently available.

Increasing the throughput requirements to 10^7 bps will stretch the current capabilities in some areas. One exception is the space-to-ground link, in which capacities of 100 Mbps are currently available. While magnetic recording media can handle I/O rates of 10^7 bps, the annual volume of 10^{14} bits will require over 100,000 tapes per year (CD ROMs cannot handle input rates of 10^7bps). Near-real-time processing and distribution of data to users still might be feasible as long as a single user does not demand access to all the data over extended periods of time. Processing speeds of 100 MIPS to handle level-zero processing, as well as storage requirements of over 100,000 PSUs per year, present some major problems using projections of current technology.

Data rates of the order of 10^8 bps present possibly insurmountable problems and challenges. Processing speeds of over 1,000 MIPS, and I/O rates of 100 Mbps into and from storage media, are difficult to achieve unless parallel-processing techniques are used. Even then, the number of PSUs will be of the (unmanageable) order of 10^6 units per year. Near real time distribution of data to users may not be economically feasible at these rates.

We do not anticipate an exponential growth in the I/O rates and storage capacities of magnetic media (or CD ROMs), or throughput rates of contemporary production networks. Specially designed multichannel magnetic recorders or very-high-speed integrated circuit (VHSIC) memories may provide a means to capture and process short bursts of data at rates of 10^8 bps. However, current technology, as well as what is projected to be available in the time frame being considered, cannot support the processing, storage, and distribution of data at sustained rates of 10^8 bps or higher.

The need for data rates of 10^8 bps or higher originates from high-resolution imaging sensors, such as multichannel spectral scanners (MSS), thematic mappers (TM), and synthetic aperture radars (SAR). There are two possible solutions to the problems created by these high-data-rate sensors. First, image data is highly redundant and data-compression schemes can be used to reduce the data rates by almost one to two orders of magnitude. Commercial coder-decoder (CODEC) devices are currently used in a variety of applications for data compression and reconstruction. In NASA systems, compression may take place on the space platform or on the ground where the level-zero processing is done. Fairly simple spatial and spectral compression algorithms can be applied to data streams of 10^8 bps to reduce the rate to 10^6 to 10^7 bps.

While compression algorithms have been developed and applied to MSS image data, new algorithms need to be developed for data from SAR and other sensors whose statistics are quite different from those of MSS data. Once successful algorithms are applied to the outputs of high-data-rate sensors, the resulting reduced data rates can be handled with existing technology. The development and application of data-compression techniques should be coordinated carefully with the user community, which traditionally takes the view that nobody should "mess around" with the data. They should be convinced that some trade-offs have to be made in order to maintain high throughputs over long periods of time. If the option to transmit uncompressed data over short periods of time, when needed, is maintained, the Committee believes that users can be convinced to accept compressed data (user involvement was discussed in Chapter V).

The data-compression issue may have to be looked at in the broader context of data or bandwidth management. Issues such as compressing data onboard versus compressing it on the ground, and using an "expert system" onboard to extract information and make decisions about how much data from each instrument to transmit to the ground, need continued study and analysis. At the higher data rates ($>10^8$ bps), the onboard processing requirements to implement any kind of "expert system" might require processing speeds in excess of 1,000 MIPS and may not be cost-effective. The cost trade-off between introducing additional processing requirements and savings that might result from reduced costs for storage and distribution must be analyzed carefully.

An alternate approach is to consider analog (or hybrid) recording techniques for storage purposes. Consider, for example, a standard TV signal which has a bandwidth of about 5 Megahertz (MHz). If this signal is digitized, the data rate required will be of the order of 10^8 Mbps without compression. Digital recording at this rate for as little as an hour will produce hundreds of digital magnetic tapes. However, several hours of the analog TV signal can be recorded on a single $4 VHS tape with a $200 recorder! Now, while digitizing facilitates easy multiplexing and transmission over long and noisy communication links, there are no significant advantages that warrant digital recording. The CD ROM technology does not provide any attractive solution to high-volume, low-demand applications. It is most effective for low, continuous throughput and high demand (several hundred copies distributed) applications.

The Committee sees promise in the use of commercially available recording technologies such as large-bandwidth analog, hybrid magnetic recording, or optical technologies. While analog or hybrid recording using magnetic tapes provides high throughput and capacities, random access to recorded data is not yet possible. Laser-vision and laser-video disks offer capacities and throughputs that are much higher than those of CD ROMs. Even though the throughput and capacities of laser-vision and laser-video disks may not be as high as analog magnetic tapes, they do provide random-access capabilities. The throughput and capacities of video disks are an order of magnitude higher than those of CD ROMs; hence, the video-disk technology should be monitored.

Limitations of Commercial Database Management Systems (DBMS). Based on briefings from NASA personnel, the Committee understands that during the next decade, NASA's mission-specific data systems will be replaced by more generic, multi-disciplinary DBMSs. Data systems can be characterized as those where the users of the system are responsible for providing all desired management of the data, whereas DBMSs provide generic management capabilities as an integral part of the database system. The commercial world successfully underwent this transition some years ago, and it is evident that the engineering and scientific worlds are undergoing a similar transition today. Equally important, major standardization activities relative to DBMSs and associated capabilities (e.g., query languages, report writing facilities) are gaining in momentum. The advent of relational-based systems has been a major factor in the drive toward standardization and will provide a vendor-independent base for future database management systems technology. The Committee also believes that OSSA and its constituent program and project offices should focus on using, to the greatest extent possible, commercially-available DBMSs or derivatives thereof, rather than spend excessive amounts of resources in developing their own.

However, while commercially available DBMSs will provide a comprehensive set of data management facilities, there remain a number of areas in which these systems fall short of meeting the needs of the engineering and scientific communities for management of large volumes of space-derived data. In conjunction with NOAA, NSF, and the community of vendors and standards organizations, NASA/OSSA should focus on this shortcoming, and encourage the private sector and the standards organizations to develop appropriate solutions. Some of this is already being done: the agreement reached between NASA and NSF in NSF's supercomputer initiative is a major step in this direction. Many of the supercomputer centers will be extending commercially available database management systems to provide those facilities required for the target engineering and scientific communities. Additional efforts of this type are required.

The Committee believes the major areas to be addressed are the following:

1. Performance. Much of the past reluctance of the engineering and scientific communities to adopt commercially available DBMSs has been the lack of numerically intensive computational performance available through the use of these systems. There has been an acceptance of this deficiency and much work is now underway to provide the necessary levels of performance. OSSA and its constituent user communities should quantify their performance requirements and make them known to vendors and other interested parties (e.g., the NSF).

2. Very large databases. Closely associated with the performance question discussed above is the question of the ability to handle very large databases. Traditional, commercially oriented DBMSs have not proven themselves to be particularly well suited to dealing with the massive amounts of data that normally are dealt with by the engineer or scientist. However, this shortcoming has indeed been recognized and much research is currently under way to improve the ability of DBMSs to deal effectively with very large databases, either directly or through the use of auxiliary processors.

3. Data definition capabilities. Commercial DBMSs have focused primarily on data-definitional facilities that have been oriented to the commercial world. These have proven not to be adequate for the engineering or scientific user. OSSA should understand better the needs of its user base in this area and transmit those needs to the appropriate standards organizations and vendors.

4. Data interchange. To achieve even a primitive level of interoperability, data interchange agreements must be formulated and agreed upon. These agreements or standards must be as non-constricting as possible; therefore, the Committee recommends that these standards be based on the notion of self-defining data (that is, data wherein the definition of the content of the data record is contained within the record itself). While we saw some indication of a beginning of this in the EOS project, it needs to be focused upon on a much broader base with a much higher assigned priority.

5. Directories and catalogs. The Committee has previously noted in this report the central role to be played by directories. We believe that effective and efficient directory management capabilities (including abilities to these directories) will be a key factor in achieving systems interoperability. User requirements for both directory content and directory management should be gathered, analyzed, and submitted to vendors and appropriate standards organizations for consideration and adoption.

6. Distributed Systems. It is inevitable that NASA scientists will be involved at a global level with a hierarchy of systems, with much distribution of both data and processing being both desirable and necessary. Fundamental architectural decisions, accommodating heterogenous systems and vendors, should be dealt with immediately. For example, will control information and responsibility be centrally managed or distributed? What will be the capabilities for shipping data to work and/or work to data?

PEAK DATA RATE TIME PROFILE

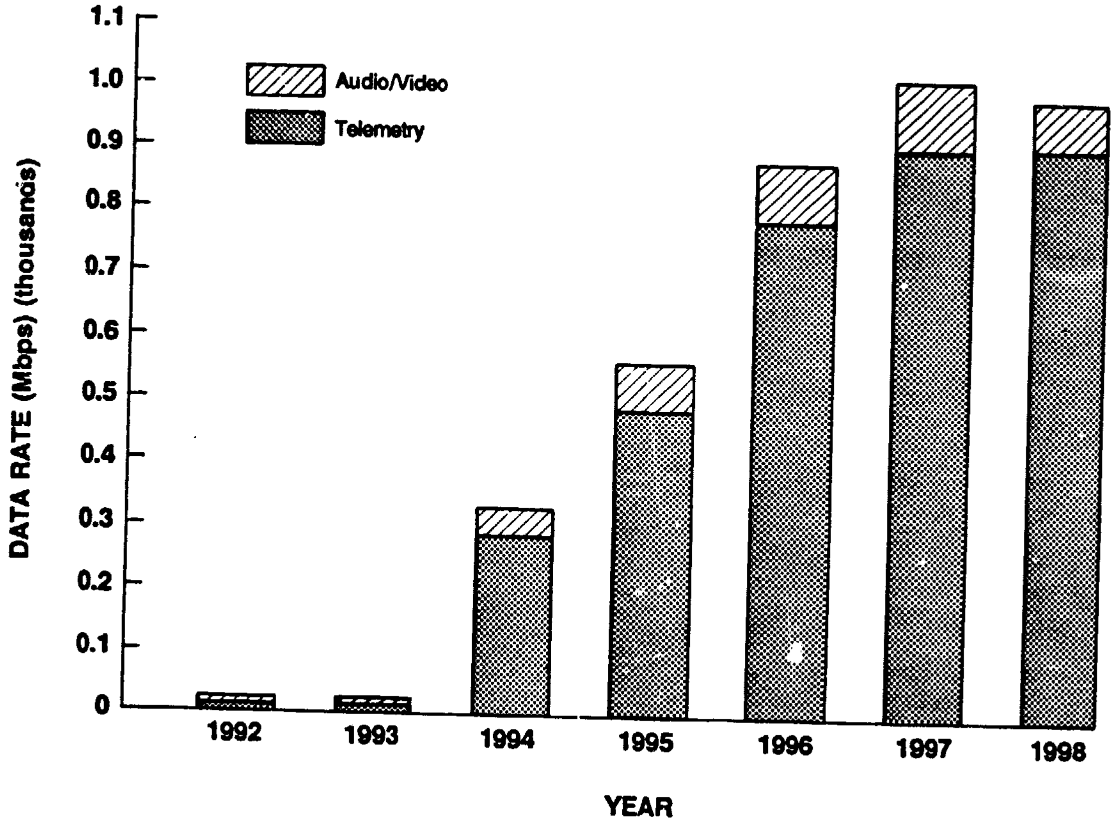

FIGURE 5

AVERAGE DATA RATE TIME PROFILE

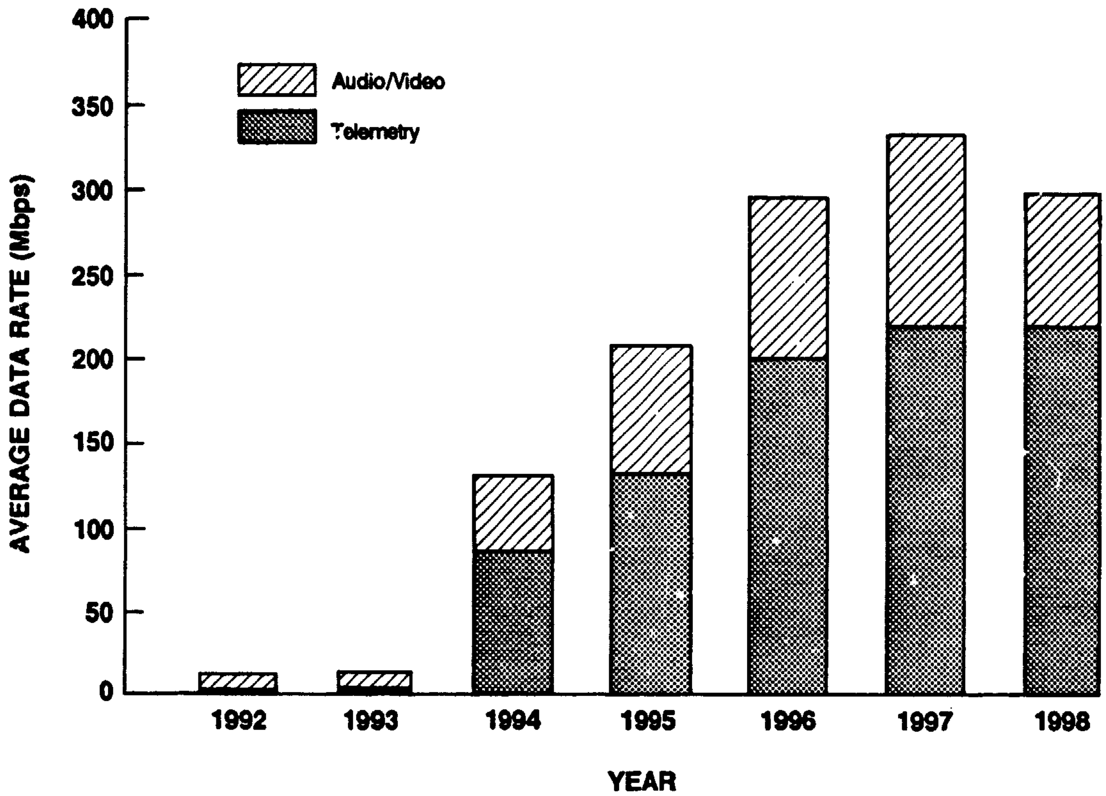

FIGURE 6

DAILY DATA VOLUME TIME PROFILE

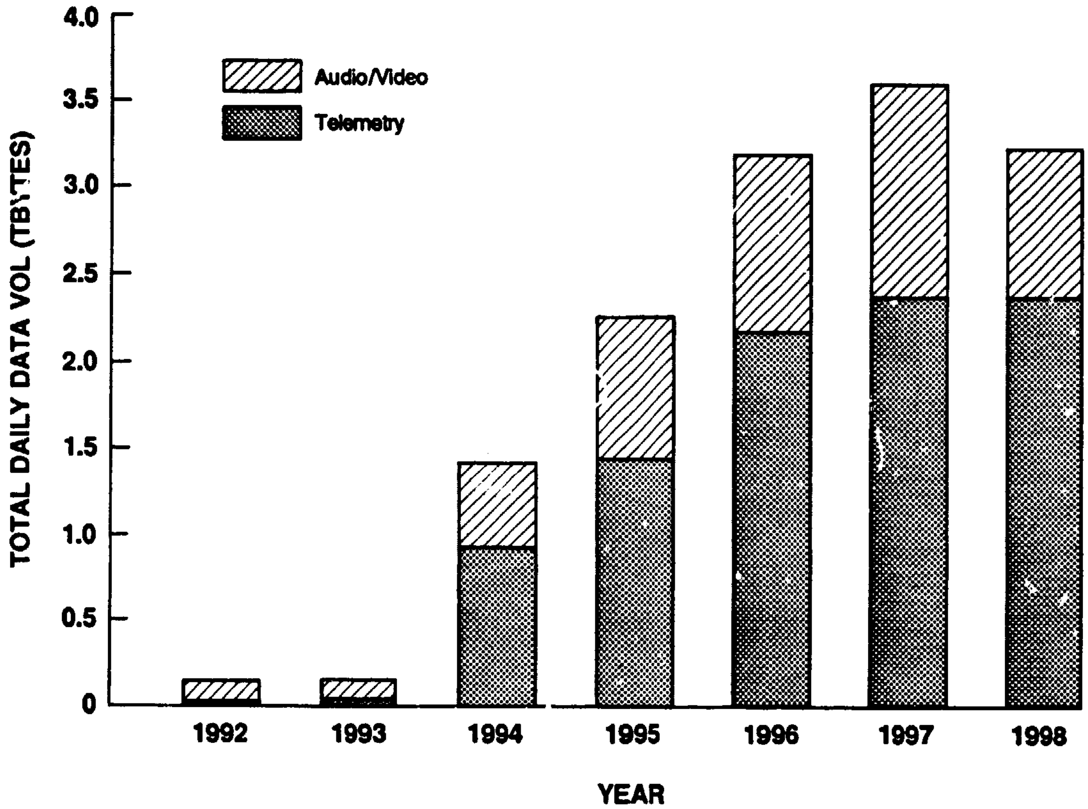

FIGURE 7

Table 2

MISSION DAILY DATA VOLUME (GIGABYTES) TIME PROFILE

Instrument	Space Vehicle	Sponsor Agency	Peak Data Rate (Mbps)	Duty Cycle P(T)	Average Data Rate (Mbps)	YEAR 1992	1993	1994	1995	1996	1997	1998
Audio/Video	SS	NASA	Variable	1.00	Variable	118.80	118.80	486.00	820.80	1015.20	1220.40	853.20
ASO	SS	NASA	50.00	0.67	33.33			359.96	359.96	359.96	359.96	359.96
AT	SS	NASA	3.00	0.50	1.50			16.20	16.20	16.20	16.20	16.20
STO	SS	NASA	10.00	0.25	2.50	27.00	27.00	27.00	27.00	27.00	27.00	27.00
Sensor	SS	NASA	120.00	0.15	18.00						194.40	194.40
HST	FF	NASA	1.02	0.21	0.21	2.30	2.30	2.30	2.30	2.30	2.30	2.30
LASA-B	ESA POP	NASA	1.00	0.75	0.75				8.10	8.10	8.10	8.10
SEASAR	ESA POP	NOAA	200.00	0.23	46.00				496.80	496.80	496.80	496.80
Spectr	ESA POP	Foreign	2.00	0.23	0.46							2.16
MODIS	EOS POP	NASA	5.00	1.00	5.00			54.00	54.00	54.00	54.00	54.00
MRIR	EOS POP	NOAA	21.00	1.00	21.00			226.80	226.80	226.80	226.80	226.80
VIS	EOS POP	NASA	2.00	1.00	2.00			21.60	21.60	21.60	21.60	21.60
ST(P)	EOS POP	NOAA	2.00	0.66	1.32		14.26	14.26	14.26	14.26	14.26	14.26
SAR	EOS POP	NASA	300.00	0.23	67.50					729.00	729.00	729.00
HIRIS	EOS POP	NASA	160.00	0.10	16.00			172.80	172.80	172.80	172.80	172.80
TIMS	EOS POP	NASA	29.00	0.10	2.90			32.40	32.40	32.40	32.40	32.40
AXAF	US COP	NASA	0.06	0.21	0.01		0.15	0.15	0.15	0.15	0.15	0.15
SIRTF	US COP	NASA	2.00	0.21	0.42			4.54	4.54	4.54	4.54	4.54
TOTAL DAILY DATA VOLUME (GBYTES)						148.10	162.51	1418.01	2257.71	3181.11	3580.71	3215.67
Audio/Video DATA VOLUME (GBYTES)						118.80	118.80	486.00	820.80	1015.20	1220.40	853.20
Telemetry DATA VOLUME (GBYTES)						29.30	43.71	932.01	1436.91	2165.91	2360.31	2362.47

NOTE: 1. DAILY DATA VOLUME = Average Data Rate x 3600 x 24 (Converted to Gigabytes)

Appendix A

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Appendix B

ACRONYMS AND ABBREVIATIONS USED IN THIS REPORT

AVHRR	Advanced Very High Resolution Radiometer
BPI	Bits per inch
bps	Bits per second
CCITT	International Telegraph and Telephone Consultative Committee
CD	Compact disk
CDP	Concept Design Phase
CODEC	Coder-Decoder
CODMAC	Committee on Data Management and Computation (NRC)
DBMS	Data Base Management System
DoD	Department of Defense
DOE	Department of Energy
ELV	Expendable Launch Vehicle
EOIS	Earth Observing Information System
EOS	Earth Observing System
ERBE	Earth Radiation Budget Experiment
ESSC	Earth System Science Committee (NASA)
Gbps	Gigabits per second
GOES	Geostationary Operational Environmental Satellite
GSFC	Goddard Space Flight Center (NASA)
HIRIS	High Resolution Imaging Spectrometer
I/O	Input/Output
IP	Internet Protocol
ISO	Information Systems Office (NASA)
"ISO"	International Standards Organization
JPL	Jet Propulsion Laboratory (NASA)
kbps	Kilobits per second
Mbps	Megabits per second
MHz	Megahertz
MIPS	Million Instructions per second
MSS	Multispectral Scanner
NAIF	Navigation and Ancillary Information Facility
NAIS	Navigation and Ancillary Information System
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NOAA	National Oceanographic and Atmospheric Administration
NRC	National Research Council

NSF	National Science Foundation
NSSDC	National Space Sciences Data Center (NASA/GSFC)
OAST	Office of Aeronautics and Space Technology (NASA)
OSI	Open Systems Interconnection
OSSA	Office of Space Science and Applications (NASA)
OSTDS	Office of Space Tracking and Data Systems (NASA)
PCDS	Pilot Climate Data System
PDS	Planetary Data System
PI	Principal Investigator
PLDS	Pilot Land Data System
PODS	Pilot Ocean Data System
PSCN	Program Support Communications Network (NASA)
PSU	Physical Storage Unit
R&D	Research and Development
RFP	Request for Proposal
ROM	Read-Only Memory
SAIS	Science and Applications Information System
SAR	Synthetic Aperture Radar
SPAN	Space Physics Applications Network
SSB	Space Science Board (NRC)
SSIS	Space Science Information System
TCP/IP	Transport Control Protocol/Internet Protocol
THIR	Temperature-Humidity Infrared
TMIS	Technical Management Information System (NASA)
TM	Thematic Mapper
TOPEX	Topography Experiment for Ocean Circulation
TP-4	Transport Protocol 4
UARS	Upper Atmosphere Research Satellite
USDA	U. S. Department of Agriculture
USGS	U. S. Geologic Survey
VHSIC	Very-High-Speed Integrated Circuit