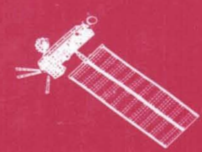
EOS 1991 Reference Handbook

NASA

Goddard Space Flight Center



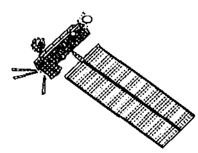
EOS

EARTH OBSERVING SYSTEM

MAY 1991

EOS Reference Handbook

NASA
Goddard Space
Flight Center



EOS

EARTH OBSERVING SYSTEM

This edition of the *EOS Reference Handbook* reflects the state of the program as of April 1991. Instrument writeups have been included only for those that were officially confirmed for EOS-A1 in February 1991, and those under consideration for the EOS-B series. The Mission Elements section has been expanded greatly, offering information on candidate instruments and the satellites to be contributed by the International Partners. All other sections have been redrafted as deemed appropriate by EOS management. To keep pace with the dynamic evolution of the program, updated editions will be forthcoming on an annual basis.

Acknowledgement must be given to the American Institute of Aeronautics and Astronautics, which granted permission to excerpt materials from a paper (AIAA-90-3638) presented at the Space Programs and Technologies Conference, held in Huntsville, Alabama, on September 25-28, 1990.

Special thanks must be extended to those individuals who made substantial contributions to the *1991 EOS Reference Handbook*: David Dokken (editor), Elias Fernandez (graphics designer), Mathew Schwaller, Lisa Grove, Lisa Shaffer, Mitch Hobish, Jeff Dozier, Larry McGoldrick, and Nina Gregoire.

TABLE OF CONTENTS

Introduction	2
The Global Change Research Program	5
EOS Goal and Objectives	9
Primary EOS Mission Requirements	10
EOS Science	11
EOS Data and Information System (EOSDIS) Architecture	12
Data Policy	18
EOS Observatories	20
International Cooperation	23
Plans and Status	24
Role of the National Oceanic and Atmospheric Administration	25
Global Change Fellowship Program	26
Management of EOS	29
Mission Elements	33
EOS Instruments	45
Interdisciplinary Science Investigations	105
Points of Contact	137
Acronyms and Abbreviations	141

List of Figures

1. Global Change Science Priorities	7
2. EOS as an Element of the GCRP and IGBP	8
3. EOSDIS Architecture	13
4. NASA Headquarters Earth Science and Applications Division	30
5. The EOS Project Office	31
6. The EOS-A Observatory	34

List of Tables

1. 1990 Global Change Fellowship Recipients	28
2. Proposed Instrument Configuration	32

EARTH OBSERVING SYSTEM

BACKGROUND

We already know from geological investigations that the Earth has undergone significant changes in its physical configuration since the time of its formation some 4.5 billion years ago. Indeed, the entire history of the Earth should be seen as a dynamic continuum, with changes taking place at all time scales. The dynamic character of the Earth makes it difficult and interesting from the scientific viewpoint. What is disturbing, however, is that there now exist data that indicate that the rate of change of several key components of the Earth system is increasing, and that human activity is a likely impetus for this increased rate of change. Changes are now occurring so rapidly that within the span of a single human lifetime we can measure significant ecological and economic effects on our home planet.

To monitor these perceived changes, a baseline of "normal" performance characteristics must be obtained. For the Earth, these baseline characteristics are needed on a global scale and over a long enough period of time that the variation imposed by seasonal variations and other cyclical or periodic events may be included in analyses. These observations must provide both a characterization of the state of the whole planet and detailed measurement of its regional variations. They must also enable quantification of the processes that govern the Earth system. Remote sensing of the Earth's environment from space provides the only truly global perspective available, although making the full set of observations goes well beyond the capabilities of any single satellite and many of the detailed measurements can only be made *in situ*. In order to obtain the global perspective, we must use a polar-orbiting observation platform; equatorial or near-equatorial orbits will not allow us to view the entire Earth. To provide the range of cyclical or periodic events, the duration of the observations must include a solar cycle and several El Niño events.

In short, then, we must begin to look at the Earth as a complex, integrated system. This requires suitable data collection in such areas as the geosphere, hydrosphere, atmosphere, cryosphere, and biosphere. Indeed, not only must we address these disciplines, but we must begin to understand the complex interactions between them, so that we can begin to comprehend the Earth's behavior.

THE EARTH OBSERVING SYSTEM

The National Aeronautics and Space Administration (NASA) has a history rich in planetary exploration, but, ironically, has not devoted as much attention to developing a detailed understanding of our own planet. With the inception of the U.S. Global Change Research Program (GCRP), NASA, along with several other Government agencies, has been charged with the task of addressing this lack of information. NASA's institutional response—the Mission to Planet Earth—will consist of a series of scientific and flight opportunities known collectively as the Earth Observing System (EOS).

The EOS mission combines the means for making observations and interpreting data with a scientific research effort to ensure that the planning and execution of the mission fulfills its intended purpose. This integrated approach is best characterized as an information system providing the geophysical, chemical, and biological information necessary for intense study of planet Earth. The EOS information system will build up over 10 years, then function for at least 15 years at its full capacity to allow accurate modeling of the processes that control the environment.

Designing and implementing the Earth Observing System is a tremendous task, one that the United States as a nation cannot hope to accomplish alone. Of necessity, it becomes an international effort. The EOS program involves the cooperation of the United States, the European Space Agency (ESA), and the Japanese National Space Development Agency (NASDA). As we attempt to understand the Earth's processes on a global scale, political and economic boundaries cannot be allowed to interfere with this important effort. The science and technology is available to begin the measurement and analysis of the Earth system; we have but to commit ourselves to the task, and to begin.

THE BUILDING BLOCKS OF EOS

The EOS mission is made up of three primary components:

- The EOS Scientific Research Program
- The EOS Data and Information System (EOSDIS)
- The EOS Observatories.

EOS SCIENTIFIC RESEARCH PROGRAM

The foundation of EOS is its scientific research. This effort is already underway, building on and complementing the Earth science research efforts of NASA, other U.S. research agencies, and their international counterparts. Within the U.S., this coordination is taking shape under the aegis of the U.S. GCRP, with coordination on the international level through the International Geosphere-Biosphere Program (IGBP) and the World Climate Research Program (WCRP).

EOS research currently focuses on:

- Use of existing satellite data
- Preparation for use of new types of data expected from satellite missions preceding EOS and from new aircraft instruments providing a preview of EOS capabilities
- Determination of detailed requirements for future observations
- Development of numerical models that can assimilate or help interpret current and future data sets.

The insights from these research activities are guiding the development of the EOS observatories and the EOSDIS. Through an EOS Graduate Fellowship Program and the involvement of graduate and postdoctoral students in EOS research, provision will be made for growth in the number of Earth scientists ready to use EOS data.

EOS DATA AND INFORMATION SYSTEM

A fundamental goal of the EOS program is to enhance the use of EOS data by the research community and cooperative interactions within this community. Past experience has shown that data systems are more effective when they are developed through an organic process involving active user participation. Thus, EOSDIS plans call for an evolutionary developmental approach, with extensive input from and testing by the research community. Functionally, EOSDIS will provide computing and networking facilities supporting EOS research activities, including data interpretation and modeling; processing, distribution, and archiving of EOS data; and command and control of the EOS observatories.

The EOSDIS development effort formally began with the EOS new start in FY 1991. Initial efforts will ensure that existing Earth science and applications data systems are adequately supported to work with currently available data. Where appropriate, these systems will evolve into nodes of a distributed EOSDIS. This step will be complemented by investment in computing facilities supporting the many individual EOS research activities. Building on this initial experience, an experimental version of the EOSDIS processing, distribution, and archiving activities will be put in place for testing by the research community. This early system will also provide user services for existing data. Based on user feedback and the results of an ongoing prototyping effort, the EOSDIS will achieve full functionality well before the launch of the first EOS platform. The full scope of EOSDIS will be made available for use in testing the EOS observatories and instrument algorithms, as well as for enhanced support of ongoing EOS research. After launch, EOSDIS will continue to evolve and grow in response to lessons learned through its use. This continuing evolution will permit exploitation of advances in data system technologies.

THE EOS OBSERVATORIES

In parallel with EOSDIS development, the EOS observatories system will be realized. The capabilities of the observatories are determined by the individual instruments and their deployment in orbit. The EOS instruments are designed to measure the following environmental variables:

- Cloud properties
- Energy exchange between Earth and space
- Surface temperature
- Structure, composition, and dynamics of the atmosphere, winds, lightning, and precipitation
- Accumulation and ablation of snow
- Biological activity on land and in near-surface waters
- Circulation of the oceans
- Exchange of energy, momentum, and gases between the Earth's surface and atmosphere
- Structure and motion of sea ice; growth, melting, and flow rates of glaciers
- Mineral composition of exposed soils and rocks
- Changes in stress and surface elevation around geologic faults
- Input of solar radiation and energetic particles to the Earth.

Full characterization of some of these elements will require sets of multiple instruments. To maximize the scientific utility of EOS data, these sets of instruments are planned for flight on the same space platform.

The EOS observatories will focus primarily on global observations from near-polar orbits at specific times of day and night. Some instruments are planned for deployment in low-inclination orbit, providing intense tropical observations and sampling of the full diurnal cycle. The number of instruments needed to supply the scientific measurements together with sampling requirements dictate most aspects of the deployment strategy for EOS, with launch logistics and engineering detail determining the rest. These requirements have led NASA and allied U.S. operational meteorological agencies, the European Space Agency, Japan, and Canada to plan a system of five polar platforms that would operate simultaneously. Two of these five platforms will be supplied by NASA as part of EOS. As originally conceived, each observatory (i.e., platform-payload combination) would be replaced at 5-year intervals to provide for 15 years of continuous data. Thus, NASA's original EOS mission obligation entails six platforms and three copies of each selected instrument. Recent studies conducted by the National Research Council (NRC) confirmed NASA's rationale for the first series of EOS platforms (EOS-A), but asked that NASA study the deployment of instruments planned for the EOS-B series. These studies will be completed in 1991.

The following sections of this Handbook provide greater detail on all aspects of the EOS program as currently envisioned. ☆

The Global Change Research Program

The U.S. Global Change Research Program is an integrated effort of nine U.S. Government agencies:

- National Aeronautics and Space Administration (NASA)
- National Science Foundation (NSF)
- Department of Commerce/National Oceanic and Atmospheric Administration (NOAA)
- Department of the Interior (DOI)
- U.S. Department of Agriculture (USDA)
- Environmental Protection Agency (EPA)
- Department of Energy (DOE)
- Smithsonian Institution
- Department of Defense (DoD).

This effort is organized under the auspices of the Committee on Earth and Environmental Sciences (CEES), which was formed by the Office of Science and Technology Policy (OSTP) under the Federal Coordinating Committee on Science, Engineering, and Technology (FCCSET).

The goal of the Global Change Research Program is to gain a predictive understanding of the interactive physical, geological, chemical, biological, and social processes that regulate the total Earth system. Enhanced knowledge thereby provides the scientific basis for national and international policy formulation and for decisions relating to natural and human-induced changes in the global environment, including regional impacts. This goal can best be achieved through cooperation with global change research activities of all nations, which encompass many organizations and programs. The GCRP has been established in cooperation with the U.S. and international scientific communities, through the National Academy of Sciences (NAS) and the International Council of Scientific Unions (ICSU). The U.S. GCRP is also linked internationally to intergovernmental organizations—such as the World Meteorological Organization (WMO), the United Nations Environment Program (UNEP), and the Intergovernmental Oceanographic Commission (IOC)—and to a number of agencies of other governments through informal groups such as the Committee on Earth Observations Satellites (CEOS).

EOS is NASA's major contribution to the U.S. GCRP, serving as the cornerstone of a long-term program to document global change. For a comprehensive overview of U.S. involvement in this international endeavor, the reader is referred to *Our Changing Planet: The FY 1992 Research Plan*, which provides a rubric for the overall U.S. research program. This document identifies the key scientific questions, the priorities among research needs, and the specific roles of the partner agencies. As delineated in this GCRP plan, three science objectives serve as the integrating priorities for the program, as follows:

- Establishment of an integrated, comprehensive, long-term program of documenting the Earth system on a global scale through
  - Observational programs
  - Data management systems
- Management of a program of focused studies to improve our understanding of the physical, geological, chemical, biological, and social elements that influence Earth system processes and trends on global and regional scales
- Development of integrated conceptual and predictive Earth system models.

Figure 1 shows the seven science priority areas that comprise the overall scientific research effort. Topics within each area are listed in priority order. Although all the research topics listed prove essential in generating an accurate perspective of the Earth as an integrated system, there is a general sense that priority decreases as one moves from left to right across this figure.

The EOS observatories constitute most of the space segment of the GCRP observational program, with the EOSDIS providing the framework for a global change data management system. The EOS interdisciplinary investigations that comprise a major portion of the EOS science program will make significant contributions to the understanding of Earth system processes and to the development of Earth system models.

The international coordination of global change research, and the role of EOS, are shown in Figure 2. In addition to broad programmatic coordination through NAS and ICSU, the NAS Committee on Global Change works with the IGBP Global Change Committee in shaping U.S. GCRP and IGBP policy initiatives. The space observing capabilities of the international community and their related data management and calibration/validation activities are coordinated at an agency-to-agency level through CEOS. More detailed coordination efforts focused on EOS and its European, Japanese, and Canadian counterpart programs takes place in the Earth Observations International Coordination Working Group (EO-ICWG), which is described in the International Cooperation section. ☆

Figure 1 Global Change Science Priorities

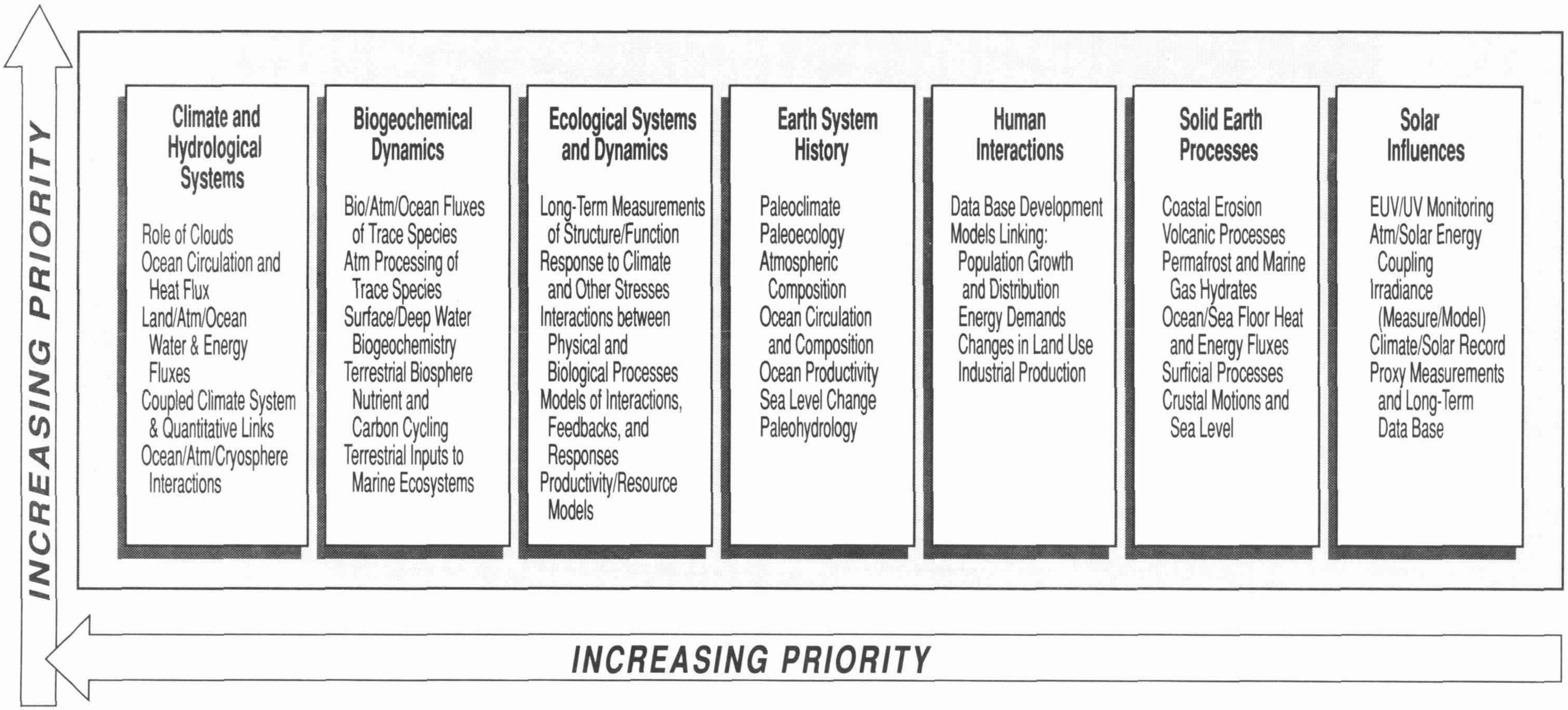
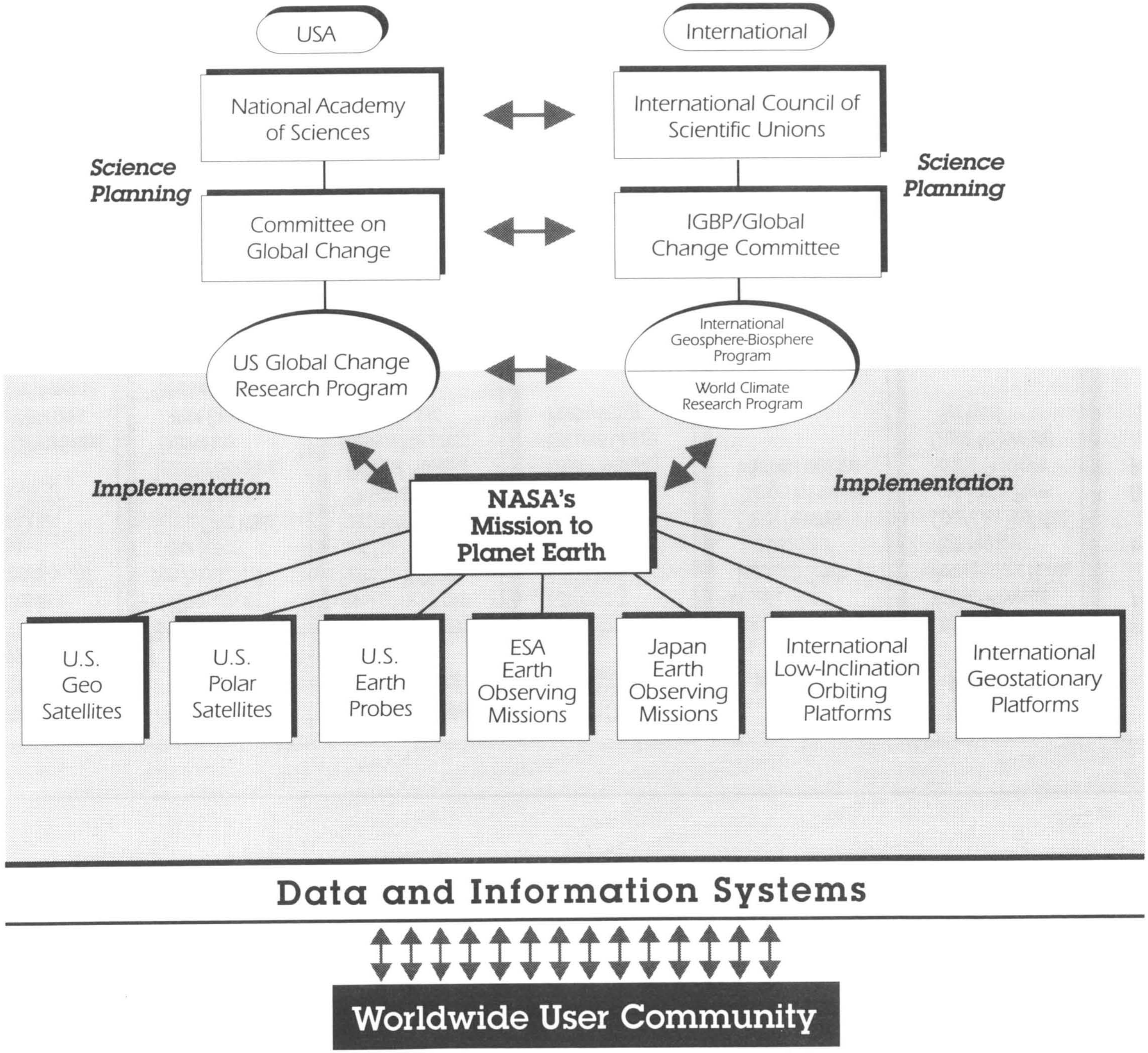


Figure 2 EOS as an Element of the GCRP and IGBP



EOS Goal and Objectives

The goal of the EOS science mission is to advance understanding of the entire Earth system on the global scale, by developing a deeper comprehension of the components of that system, the interactions among them, and how the Earth system is changing. To quantify changes in the Earth system, EOS will provide systematic, continuing observations from low Earth orbit for a minimum of 15 years.

Mission objectives in support of this goal are:

- To create an integrated scientific observing system that will enable multidisciplinary study of the Earth's critical, life-enabling, interrelated processes involving the atmosphere, oceans, land surface, polar regions, and solid Earth, and the dynamic and energetic interactions between them.

- To develop a comprehensive data and information system, including a data retrieval and processing system, to serve the needs of scientists performing an integrated multidisciplinary study of planet Earth.

- To acquire and assemble a global database for remote sensing measurements from space over a decade or more to enable definitive and conclusive studies of Earth system science attributes, including (but not limited to):

  - Global distribution of energy input to and energy output from the Earth

  - Structure, state variables, composition, and dynamics of the atmosphere from the ground to the mesopause

  - Physical and biological structure, state, composition, and dynamics of the land surface, including terrestrial and inland water ecosystems

  - Rates, important sources and sinks, and key components and processes of the Earth's biogeochemical cycles

  - Circulation, surface temperature, wind stress and sea state, and the biological activity of the oceans

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

  - Global rates, amounts, and distribution of precipitation

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

Primary EOS Mission Requirements

- Provide long-term (15-year) observing capability
- Obtain at least 1 decade of overlapping, calibrated data from the full suite of EOS observatories providing long-term, simultaneous observations of phenomena on local, regional, and global scales
- Globally characterize the highly variable aspects of the Earth system every 1 to 3 days
- Make all EOS data and derived data products readily available in a timely manner to all approved users, with no preference given to EOS investigators
- Support the communication and exchange of research findings that result from use of EOS data or are produced by EOS investigations
- Maintain continuity in essential global change measurements of existing and planned missions (e.g., UARS, TOPEX/Poseidon)
- For instruments having the potential to fly on multiple spacecraft, use instrument interfaces that are compatible with the ESA polar platforms and future NOAA operational satellites
- Support the overall U.S. Global Change Research Program ✩

EOS Science

EOS and other elements of the Mission to Planet Earth program (i.e., Earth Probes and geostationary satellites) will provide the comprehensive global observations of Earth necessary to understand how the processes that govern global change interact as parts of the Earth system. This understanding is critical to the development of models for predicting future environmental change on local, regional, and global scales.

To obtain basic information about the state of the Earth, appropriate instruments must be deployed both on the Earth's surface and in space. Satellite remote sensing provides global and long-term continuous measurements for monitoring the entire planet. Surface-based measurements are required to validate the space-based observations, to provide more detailed studies, and to observe those processes not accessible from space. This suite of coordinated investigations underlies EOS science.

EOS science is guided by the EOS Investigator Working Group (IWG), which includes all the selected Interdisciplinary Principal Investigators (PIs), Instrument PIs, lead U.S. Co-Investigators for non-U.S. investigations, and Facility Instrument Team Leaders. See the EOS Observatories section for definitions of Facility Instruments and Instrument Investigations. All investigations were selected by NASA through a competitive process wherein proposals solicited from the worldwide community were peer-reviewed on the basis of scientific and technical merit. The goal and objectives of the EOS mission as stated herein are the same as those upon which solicitation of scientific participation were based. Details of the instruments and investigations selected are presented in the EOS Instruments and Interdisciplinary Investigations sections of this Handbook.

Before the selection of EOS investigations and the formation of the IWG, EOS planning was guided by a series of scientific committees and panels composed of Earth science researchers, and by the reports of these committees and panels. These reports still contain useful background information on EOS, including the observations to be made and their use in the study of the Earth system. More current information and guidance is now coming from the IWG and its panels, and various reports are anticipated over the coming years, documenting findings/recommendations and specific guidance to the EOS Project and Program Offices at NASA.

At present, the EOS IWG has established the following panels:

- Atmosphere
- Biogeochemical Cycling
- Calibration/Validation
- EOSDIS Advisory
- Facility Instruments
- Land/Biosphere
- Modeling
- Oceans
- PI Instrument
- Precision Orbit Determination/Mission Design
- Payload Advisory
- Physical Climate and Hydrology
- Solar Terrestrial
- Solid Earth.

Each panel is chaired by a member of the IWG, and these chairmen serve as the Science Executive Committee (SEC). Membership on the panels is generally open to all EOS investigators, including Co-Is on any EOS investigation and members of EOS facility instrument teams. The only restrictions on membership to date occur where conflicts of interest exist. Scientists outside the group of EOS investigators are included in the various panels.

By coordinating scientific investigations within and between national and international agencies and organizations, the goals of the U.S. GCRP will be met and, by extension, those of the IGBP as well. ☆

EOS Data and Information System (EOSDIS) Architecture

EOSDIS ARCHITECTURE
(Preliminary Design)

A high-level schematic diagram of the present EOSDIS architecture is offered as Figure 3. As EOSDIS evolves, details of this design may be modified; however, the overall concept has been studied and endorsed by two industrial teams, with the EOSDIS Science Advisory Panel actively involved in all aspects of the examination. Among the key principles guiding EOSDIS development are the following:

- EOSDIS must serve a broadly distributed Earth science community.
- The system must be designed to evolve continuously in capability.
- The processing, distribution, and archival functions of EOSDIS must be openly accessible to the research community.
- The command and control of the EOS observatories must be secure and highly reliable.

The key functional objectives of EOSDIS are to provide:

- Command and control of the NASA EOS observatories
- Processing and reprocessing of EOS data
- Data access and distribution for EOS and other NASA Earth science data
- Networking capabilities
- Transfer of data to permanent archives
- Data quality monitoring and data accounting
- Exchange of data, commands, algorithms, etc., with NOAA, ESA, Japan, Canada, and possibly others.

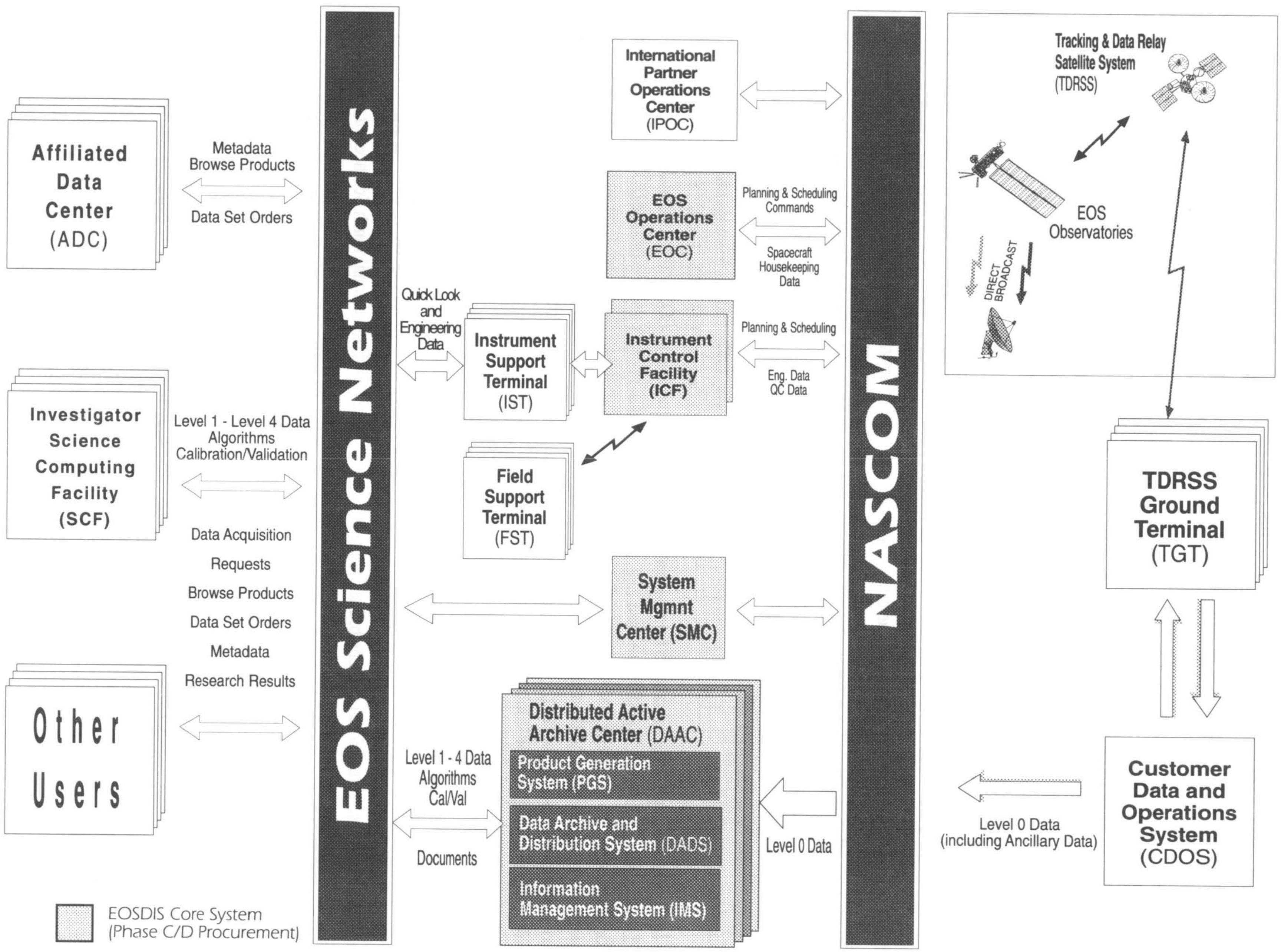
EOSDIS COMPONENTS

The EOSDIS architecture is composed of several types of elements, most of which will be geographically distributed, thereby providing resilience.

The EOS Operations Center (EOC) is responsible for mission control, mission planning and scheduling, instrument command support, and mission operations. Communications with the platforms and instruments all go through the EOC, which coordinates with external (i.e., non-EOS) systems such as the Customer Data and Operations System (CDOS), which in turn connects EOS with the Tracking and Data Relay Satellite System (TDRSS). The International Partner Operations Centers (IPOCs) perform functions similar to those of the EOC for the International Partner observatories.

The Customer Data and Operations System (CDOS) provides data capture and production processing of telemetry data from Earth-orbiting satellites. This NASA institutional facility provides for the uplink of commands through the TDRSS. Production processing involves the separation of composite downlink transfer frame data streams into individual payload/instrument data packet streams (i.e., level 0 processing, see page 17 for level definitions). The CDOS also serves as a long-term backup archive of the level 0 processed data. The uplinking of commands to and the acquisition of level 0 data from EOS instruments on the International Partner observatories will be handled via interfaces to the respective ground systems.

Figure 3 EOSDIS Architecture



The Tracking and Data Relay Satellite System (TDRSS) relays data to and from low-altitude, Earth-orbiting satellites, the Space Shuttle, and so on. This NASA system includes specialized communications satellites located in geosynchronous orbit both east and west of the continental United States (providing coverage of virtually the whole globe) and redundant TDRSS Ground Terminals (TGTs) at White Sands, New Mexico.

The Instrument Control Facility (ICF) consists of several Instrument Control Centers (ICCs). Each ICC plans and schedules instrument operations, generates and validates command sequences, provides the capability to forward commands and to store them for later transmission, monitors the health and safety of instruments, and provides instrument controllers with status information on their instruments. Two ICFs are planned: One at Goddard Space Flight Center (GSFC) and one at the Jet Propulsion Laboratory (JPL). The International Partner ICCs will perform similar functions for their instruments on EOS observatories.

The Instrument Support Terminals (ISTs) reside at Instrument PI and Team Leader sites. The ISTs are used to access ICCs for information on the health and safety of individual instruments. They enable PIs and their engineering support teams to provide command inputs to the ICCs, and to participate with instrument and mission controllers in the diagnosis and resolution of performance anomalies.

A Distributed Active Archive Center (DAAC) is an EOS-funded facility that processes, archives, and distributes EOS data and products for the duration of the EOS mission. EOS active archives are institutional responsibilities, thus distinct from facilities that are under the purview of an investigator team. An EOS DAAC contains functional elements that include a Product Generation System (PGS), a Data Archive and Distribution System (DADS), and an Information Management System (IMS). Other (non-NASA) agencies may share management and funding responsibilities for the active archives under terms of agreements negotiated with NASA. During the EOS operational lifetime and beyond, NASA may make arrangements to transfer some or all EOS data and products from EOS active archives to permanent archives.

The Product Generation System (PGS) performs data processing functions, including routine generation of standard products, quick-look products, metadata, and browse data sets. These operations also extend to reprocessing of data and retrospective production of new standard products. Computational support for other activities, including research and special product trials, can also be included in these facilities.

The Data Archive and Distribution System (DADS) is responsible for archiving and distributing EOS data and information. This includes level 0 and higher level data products, ancillary and correlative data, metadata, command histories, algorithms, documentation, and procedures for requesting special observations from EOS. Data will be distributed from DADS to EOS scientists, other EOS facilities, and other research users electronically via networks or on high-density storage media, such as optical disks, depending on the requested volume.

The Information Management System (IMS) is the user interface for EOSDIS. The IMS provides information about data, both in EOS and in external archives, on a 24-hour basis; accepts user orders for EOS data; provides information about future data acquisition and processing schedules; accepts and forwards data acquisition and processing requests; and maintains information on system status, management, and coordination.

Affiliated Data Centers (ADCs) are non-EOS data centers with which agreements will be made to provide access to non-EOS data or to special non-EOSDIS services required by the EOS program. Examples of planned ADCs include the Consortium for International Earth Science Information Networks (CIESIN), NOAA/National Environmental Satellite, Data, and Information Service (NESDIS), and the University of Wisconsin.

A Permanent Archive is a facility funded independent of the EOS budget that may take responsibility for the permanent archival of EOS data and products during and beyond the scope of the EOS mission, receiving these data and products from an EOS active archive and providing long-term access to them. Agreements with these archives will be negotiated by NASA Headquarters, with EOS Project coordination, and these agreements will become part of the EOS Project Data Management

Plan. Examples of permanent archives include the U.S. Geological Survey (USGS)/Earth Resources Observation System (EROS) Data Center (EDC) and NOAA/National Environmental Satellite, Data, and Information Service (NESDIS).

The Science Computing Facilities (SCFs) involve those capabilities provided by the EOS program to scientists at Team Member, PI, and Interdisciplinary Investigator computing facilities for development and maintenance of algorithms/software for generation of standard data products, quality control of products, data set validation, instrument calibration, scientific analysis, modeling, research, generation of special data products, instrument operations planning, and interface to scientists' institutional facilities.

Networks will be used for electronic distribution of EOS data and information to all nodes within the system and to the scientific research community at large, including the International Partners. This will be accomplished through standard network protocols, interfacing with widely used scientific networks where possible. EOSDIS networks will allow concurrent, distributed analysis of EOS data, facilitating communication between researchers as well as easing access to data sets. Audio and visual links may be incorporated to enhance this function.

Field Support Terminals (FSTs) will provide mobile communications to coordinate platform data acquisition with field experiments and the necessary display capabilities to support field campaigns.

The long-term science plan for the EOS observatories will be provided to the EOS Project by the IWG. The EOS investigators will be able to access all mission planning and scheduling information via the IMS, using their SCFs as remote interfaces. Requests for future data from instruments that require advanced scheduling will be placed through the IMS, but should be coordinated with the Instrument PI or Team Leader (e.g., by electronic mail) prior to request to ensure that it is reasonable given the overall scheduling priority guidelines for the instruments as approved by the instrument team and the IWG. The long- and short-term scheduling plan for each instrument will be the responsibility of the Instrument PI or Team Leader (working within the science plan guidance established by the IWG), who will communicate electronically with the ICC through his/her IST in order for the ICC staff to prepare the command streams that will be transmitted to the EOC and thence to the instruments on the spacecraft. Scheduling priorities will be based on the guidelines set by the IWG and carried out under the direction of the Project Scientist or his deputy who will be available onsite at the EOC.

Instrument and ancillary data transmitted to ground via TDRSS will be level 0 processed in the CDOS, and the level 0 data sent to the EOSDIS DAACs for further processing and distribution. The IMS will be updated automatically whenever new data or products are available in the DADS for distribution. Users will obtain information and place one-time or standing orders for data by interacting electronically with the IMS. They will also be able to request all supporting algorithms, models, documentation, etc., through the IMS. A user support office will be available for direct telephone or electronic mail contact concerning questions or problems with accessing the data. Each data set will also have references to the PI or team responsible for the product for further information on the data utility and production history.

Quick-look data for engineering assessment of platform and instrument performance will be routed directly to the EOC and ICCs, where 24-hour monitoring of the platform and instrument health and engineering performance can be done. Instrument PIs and Team Leaders will be able to remotely monitor information available at the ICCs through their ISTs, and will be able to communicate directly with the ICC staff in resolving instrument anomalies in near-real time. The Flight Operations Team (FOT) at the EOC will be responsible for observatory health and safety.

A support office will also be provided by EOSDIS to assist EOS investigators and their teams in developing algorithm software to run in the EOSDIS computing environment. This office will provide guidelines on coding standards and documentation, and will also organize training programs for EOS science algorithm software developers.

EOS INVESTIGATOR DATA SYSTEM RESPONSIBILITIES

The following bullets encapsulate the general responsibilities of the EOS investigators with respect to the EOSDIS. The specific responsibilities vary depending on whether an investigator is a Team Leader, Team Member, Instrument PI, or an Interdisciplinary Investigator:

- Algorithms (i.e., develop, code, debug, validate, integrate with other users of same instrument, optimize for EOSDIS environment, document, maintain archive)
- Develop specifications for standard data products, including quick-look, quality control, and browse data products; perform ongoing scientific quality control of products
- Develop requirements for SCFs
- Deliver special products and algorithms to be archived
- Provide ongoing scientific quality control for standard products
- Provide up-to-date instrument calibration data on an ongoing basis
- Manage the collection and processing of correlative data required to calibrate or validate the data products
- Participate in mission planning and scheduling and instrument operations.

SYSTEM MANAGEMENT

EOS investigators, especially Interdisciplinary Investigators, will need to assimilate data and information from several instruments in the course of their research; furthermore, EOS algorithm software will need to be portable across different computer elements within the EOSDIS environment. Hence, the adoption and development where necessary of a suite of standards for data structures, data formats, software code, and documentation will be essential for EOSDIS. The EOS Ground Systems and Operations Project at GSFC will work with EOS investigators and the EOSDIS Science Advisory Panel in identifying and developing these standards.

EOS data will continue existing measurements, some of which extend for more than a decade. Therefore, EOSDIS will be developed in an evolutionary manner to accommodate existing data sets, as well as new EOS data when they become available. A number of existing centers, where remote sensing data are intensively and routinely analyzed into scientific products, will form the heritage for development of the EOSDIS DAACs. The design and development of EOSDIS will proceed in a series of prototypes and "builds," which will provide early functional EOSDIS elements that can be used and evaluated by scientists using pre-EOS data in readiness for EOS launch. These evolutionary EOSDIS elements will be developed with the necessary standards and interfaces required for EOSDIS to function as part of the U.S. and international global change research data system.

The timely and efficient generation of various data products requires a high degree of coordination among the various distributed elements in the system. The System Management Center (SMC) will support a variety of functions to track system-wide resources, to ensure data flow, and to perform administration and accounting. The SMC and the EOC will be located at GSFC. The ICFs will be located at GSFC and JPL. As indicated, the PGS, DADS, and IMS functions will be co-located to form DAACs at a number of sites based on discipline and scientific research expertise, existing infrastructure, and institutional commitment to the activity. As currently envisioned, the long-term responsibility for management and distribution of EOS data will be transferred to the organizations that are partners with EOS in the data system activities (e.g., NOAA and USGS). The proposed distribution of DAACs follows:

- **Upper Atmosphere, Atmospheric Dynamics, Global Biosphere, Geophysics**
  Goddard Space Flight Center—Experience with UARS, atmospheric sounding and tropospheric moisture sensing, and CZCS and AVHRR
- **Ocean Circulation, Air-Sea Interaction**
  Jet Propulsion Laboratory—Experience with Seasat, TOPEX, NSCAT, SSM/I, and NODS

- **Radiation Budget, Aerosols, Tropospheric Chemistry**
  Langley Research Center—Experience with ERBE and SAGE

- **Cryosphere (non-SAR)**
  University of Colorado
  National Snow and Ice Data Center—Experience with SMMR and SSM/I

- **Land Processes Imagery**
  EROS Data Center—Experience with Landsat and AVHRR

- **Sea Ice, Polar Processes Imagery**
  University of Alaska, Fairbanks—Experience with Alaska SAR Facility

- **Hydrology**
  Marshall Space Flight Center—Experience with WetNet.

KEY EOSDIS TERMS

Standard Data Products. Data products that are generated as part of a research investigation using EOS data, are of wide research utility, are routinely produced, and in general are produced for spatially and/or temporally extensive subsets of the data are to be considered standard data products. All EOS instruments must have standard level 1 data products, and most will have standard level 2 data products. Some EOS interdisciplinary investigations will also generate standard data products. Specifications for the set of standard data products to be generated by the EOS Project will be reviewed by the IWG and NASA Headquarters to ensure completeness and consistency in providing a comprehensive science data output for the EOS mission. Standard data products will normally be generated in the EOS PGS.

Special Data Products. Data products that are generated as part of a research investigation using EOS data and that are produced for a limited region or time period, or products that are not accepted as standard by the IWG and NASA Headquarters, are referred to as special data products. Special data products will normally be generated at investigator SCFs (provided for EOS investigators out of the EOS budget). Special products may be reclassified later as standard products upon review and approval by the IWG and NASA Headquarters; in which case, the algorithms and processing will migrate to the PGS and be placed under the appropriate configuration controls.

Level Definitions. The various levels of data referred to in this document are identical to those defined by the EOS Advisory Panel in its report and are consistent with CODMAC definitions. For some instruments, there will be no level 1B product that is distinct from the level 1A product. In these cases, the reference to level 1B data can be assumed to refer to level 1A data.

Level 0 - Reconstructed unprocessed instrument/payload data at full resolution.

Level 1A - Reconstructed unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters (i.e., platform ephemeris) computed and appended, but not applied, to the level 0 data.

Level 1B - Level 1A data that has been processed to sensor units (not all instruments will have a level 1B equivalent).

Level 2 - Derived environmental variables at the same resolution and location as the level 1 source data.

Level 3 - Variables mapped on uniform space-time grid scales, usually with some completeness and consistency.

Level 4 - Model output or results from analyses of lower level data (i.e., variables derived from multiple measurements). ☆

Data Policy

EOS data policy is designed to further the EOS objectives of acquiring a comprehensive, global, 15-year data set; maximizing data utility for scientific purposes; and simplifying long-term access to and analysis of EOS data. In pursuit of a common policy across the entire international suite of data generated during the lifetime of the mission, the following tenets have been adopted by agency decisionmakers:

- Data from EOS instruments will be acquired according to priorities recommended by the IWG and the EO-ICWG, and confirmed by NASA Headquarters.
- Where EOS sensors make site-specific observations, EOS will be an "acquire-on-demand" system. Data will only be taken in cases where there is an identified user who has requested and will analyze the data.
- All acquired EOS data will be processed at least to level 1 and archived at level 0 or at a higher level from which level 0 may be recovered.
- Raw data from instruments designated as having operational potential will be made available to NOAA at the point of receipt as soon as they are received on the ground.
- Routine processing and reprocessing of EOS data by the EOS Project to standard products at levels 2 and above will be done according to science requirements and using algorithms approved by the IWG.
- Following the post-launch checkout period, all level 1 standard products will be processed and made available by EOSDIS within 48 hours of observation; levels 2 and 3 standard products will be made available within 96 hours of observation. It is understood that some products may be needed earlier and that some standard products will require longer to generate. Modifications to these schedules will be accommodated once the processing requirements for each product are understood.
- EOS data and products will be available to all users; there will be no period of exclusive access.
- All data requests for approved research purposes will incur a modest charge consistent with the actual marginal costs of filling the request. This system will ensure reasonable allocation of EOSDIS resources, while not discouraging full use of EOS data.
- EOSDIS will provide the capability for archiving and making available all science data products, models, algorithms, and documentation generated as part of the EOS mission. All products derived from EOS data provided at the cost of reproduction and distribution and upon which refereed articles are based, including models, algorithms, and associated documentation, must be made available to the research community.
- EOSDIS will include and make available information about the data, such as quality assessments, supporting literature references, and catalog and directory entries.
- EOSDIS project management, in consultation with the IWG, will establish protocols and standards to encourage and facilitate data software exchange and interoperability.

The following three categories of users will access EOS data: Research users (including U.S. Government-sponsored and other research users), operational and environmental monitoring agency users (e.g., NOAA and EUMETSAT), and other (primarily commercial) users. A detailed data policy is being developed by NASA and its EO-ICWG partners to ensure that data from the entire suite of satellites comprising the International Earth Observing System (IEOS) will be available to all users on a consistent and fair basis through any of the partner agencies. Different arrangements are foreseen depending on the type of user.

RESEARCH USERS

NASA will select research users who propose to use EOS data in a study or investigation 1) that aims to establish facts or principles; 2) where the data may not be sold, and may be reproduced or provided only to other researchers covered by a research agreement or for whom the researcher takes responsibility; 3) where the results of the research will be submitted for publication in the scientific literature; and 4) where detailed results, including data, algorithms, and models, will be made available to the research community at the time it is accepted for publication. These users will be considered "affiliated research users," and will be required to sign a "research agreement" confirming these commitments. In exchange, they will be granted access to data from EOS and its foreign partner programs for the approved investigation at no more than the marginal cost of reproduction. The affiliated status will be in effect for the period of time specified in the written research agreement. Sanctions will be placed on those users who receive data from the EOS program under the above conditions and who subsequently violate the research agreement.

Investigators funded by NASA's EOS program will be granted the status of affiliated user. Their support will include funds for data purchases, which will be placed in accounts on EOSDIS and which will be charged for data requested. Standard data products will be available to EOS investigators no earlier than to other users. As with all other affiliated users, EOS investigators will be required to sign the research agreement and to abide by its terms. Research results from EOS investigators, including data products, algorithms, models, and associated documentation, will be returned to EOSDIS to be archived and made available to the scientific community. Non-U.S. EOS investigators selected by NASA will be subject to this same data policy, even though their funding will come from their own national sponsoring agency.

Other researchers who NASA affiliates and who sign the research agreement will have access to all EOS data required for their investigation at the marginal cost of reproduction and distribution. The same conditions apply to them as to NASA-funded EOS investigators. Research users affiliated with EOS partner agencies in Europe, Canada, and Japan will have the same access as researchers affiliated with NASA. NASA and its International Partners seek to make data available on this basis to researchers whose sponsoring agencies are openly sharing Earth science data and otherwise actively contributing to the international efforts that parallel the U.S. GCRP.

OPERATIONAL AND ENVIRONMENTAL MONITORING AGENCY USERS

Data will be made available for operational and environmental monitoring use by agencies providing public service such as weather and sea state forecasting. Operational and environmental monitoring constitutes any use of data to carry out a mandate of environmental observation and prediction as part of an agency's responsibilities to provide for the general welfare. Such use may include the routine downlink or direct broadcast of enhanced and unenhanced data in near-real-time within the operational community. Such users include those government agencies affiliated with the parties that conduct environmental monitoring and/or operational observations for the public good, and can include larger agencies to which the parties belong (e.g., WMO). Operational agencies (e.g., NOAA and EUMETSAT) may obtain real-time access through their own direct readout facilities and/or via data relay satellites. Data use shall be provided in real- or near-real-time without fee, and shall be available through international EOS archives for non-real-time users for no more than the marginal cost of reproduction and delivery, consistent with the terms of applicable research agreements.

OTHER (PRIMARILY COMMERCIAL) USERS

Commercial arrangements will be established to serve users who are not affiliated with any of the participating agencies and/or who are interested in commercial endeavors. This category encompasses those persons requesting data for scientific, operational, applications, or commercial use who are not directly represented by an EO-ICWG member, and who agree to the stipulations on data access and use as set by the EO-ICWG and the EOS program. Procedures will be in place for commercial distribution on a non-discriminatory basis to non-research/non-operational users. ☆

EOS Observatories

A common design has been chosen for all NASA polar platforms and payloads, including modularity of instruments and spacecraft subsystems. This overall approach represents a fortunate confluence of the best science strategy with the lowest likely cost and the simplest operating scenario.

Current plans for the first platform series—designated EOS-A—have been supported by a recent NRC report entitled *The U.S. Global Change Research Program: An Assessment of the FY 1991 Plan.* The study found that the rationale for the second platform series—earlier designated EOS-B—is not as strong as that for EOS-A, and suggests that NASA reexamine the EOS-B design concept. However EOS is configured, the platform series is scheduled to be joined by a dedicated EOS Synthetic Aperture Radar (EOS SAR) platform in 2000. The observational capabilities of the EOS observatories will also be supplemented by NOAA, European, and Japanese observatories planned in conjunction with EOS. The proposed payload groupings are the result of extensive analysis of accommodations, science requirements, International Partner plans, cost, schedule, and other factors.

Within the overall payload of EOS, there are sets of instruments that can complement each other in the production of desired observations. In some instances, certain instrument suites are required to yield correlative data. To do this, they must make their measurements simultaneously. These sets dictate certain minimum payload groupings around which alternative scenarios have been built and assessed. The time scales for significant variations in the phenomena being observed define the meaning of simultaneous.

For EOS, there are four levels of simultaneity, which are detailed in the following paragraphs in the order of increasing tightness in the requirement.

1) All EOS instruments need to be in orbit at the same time. This enables many of the variable components of the Earth system to be characterized globally every 1 to 3 days. This requirement is the reason behind the extensive set of planned observing capabilities. While many aspects of the Earth do not change on the time scale of days, all EOS instruments observe dynamic phenomena that do change rapidly.

2) The atmosphere changes on time scales as short as 10 seconds. Changes in temperature, aerosol concentrations, water vapor distributions, and clouds can significantly affect the atmospheric contribution to signals received by optical instruments. This imposes simultaneity requirements on three separate sets of instruments to make their observations within a minute of one another and from the same perspective. The first group of these instruments includes those that measure the troposphere (i.e., MODIS, MISR, EOSP, MIMR, LIS, AIRS, AMSU-A, and MHS). If observations are made at the same time, data from these instruments can be combined to produce improved algorithms for atmospheric temperature and moisture profiles, cloud properties, aerosol column densities, and instantaneous rain rates. This list must be augmented with HIRIS and ASTER to provide finer spatial resolution measurements to examine sub-pixel variations within the measurements of these other sensors.

The second grouping includes the optical surface imagers (i.e., MODIS, HIRIS, ASTER, MISR, and EOSP). Although each of these imagers operates at different spatial resolutions, they share specific spectral bands. Surface imaging optical instruments always employ atmospheric corrections. If MODIS and HIRIS or ASTER view the surface through the same atmosphere (i.e., simultaneously and from the same perspective), their data will be directly intercomparable before atmospheric corrections are applied. This will remove a major source of potential ambiguity from the results of such intercomparisons. Furthermore, the atmospheric corrections of the optical surface imagers may be aided by data from the atmospheric sensors in the first group.

The third group of instruments are those that measure the different components of stratospheric chemical composition (i.e., HIRDLS, MLS, SAFIRE, and SWIRLS). If these instruments view the same stratospheric air mass at the same time, chemical concentrations from one instrument can be reasonably combined with those from another for a more comprehensive set of observations to use in comparisons with localized photochemical models.

3) Vegetation canopies respond to environmental conditions on many time scales, but typical responses to drying conditions and variations in insolation may take as little as an hour. Consequently, those instruments used to study terrestrial vegetation need to make their measurements of a given site within an hour. This set of instruments includes all surface imagers within the proposed EOS payload (i.e., MODIS, HIRIS, ASTER, MIMR, MISR, and EOSP). If these instruments are on platforms in the same orbit, even if they are on more than one platform, they can have the opportunity to view the same sites within 1 hour of each other. If they are flown in different orbits, there would only be intermittent opportunities for simultaneous viewing within the time requirement.

4) Measurements produced by ALT and GLRS both require precise knowledge of spacecraft location. The GGI instrument on EOS is intended to provide this information. Flying these three devices on the same spacecraft would allow them to share spacecraft location information.

There are also benefits from the flight of radar altimeters and scatterometers with passive microwave imagers. In the case of ALT, the requirement is for a purely nadir-viewing radiometer to correct the range delay caused by tropospheric water vapor. This can be accomplished with a modest microwave radiometer; such a radiometer will be included with the EOS radar altimeter. The accuracy of scatterometer wind measurements is affected by the variable attenuation of its radar pulses by atmospheric liquid water and vapor. Thus, the scatterometer observations will be improved if STIKSCAT is flown on the same platform as MIMR, which measures atmospheric water.

The requirements imposed by the rapidly changing atmosphere have significant impact on the logistics of EOS. Flying optical surface imagers and tropospheric measuring devices so that they view the same atmosphere within 1 minute effectively dictates that they be accommodated on the same spacecraft. Although mass and power figures for this collection of instruments are still preliminary, it is expected that together they will weigh between 2,800 and 3,000 kg, and require 2.5 to 3 kW of average power. A spacecraft that can supply these resources would be larger than the Upper Atmosphere Research Satellite (UARS), with roughly four times the power and with the capability to manage over 10,000 times more data. Such a system would also require a Titan IV launch vehicle. The NASA polar platforms are designed to meet this need.

Global coverage from EOS dictates that these instruments be flown in a near-polar orbit. Such orbits are either sun-synchronous or nearly so, with the latter yielding an observation window that cycles through all times of day over a period of 3 to 6 months or more. To avoid aliasing EOS observations with the combined effects of diurnal and seasonal effects, sun-synchronous orbits have been selected for EOS. The 705-km, 98.2° inclination orbit planned for EOS will provide a quasi-2-day repeat pattern for frequent global coverage, while being in an altitude range acceptable to both wide-swath-width and high-resolution instruments.

The equator crossing time for EOS has been selected as 1:30 p.m. ascending node. This choice ensures strong solar illumination to improve the signal-to-noise performance of instruments measuring reflected sunlight. It is also designed to provide observations of terrestrial vegetation under conditions of near-maximum thermal and water stress. With this choice, NASA's EOS platform will provide combined high- and moderate-resolution imagery to complement the morning crossing time measurements of SPOT and Landsat at high resolution, and the moderate-resolution imagery planned for the ESA polar platform. This choice of orbit also means that those EOS instruments with operational potential will be flown under conditions that are close to those of the primary NOAA polar operational mission.

EOS will carry two classes of instruments: Facility Instruments supplied by NASA in response to the general mission, and PI Instruments selected through competition and aimed at the specific focused research interests of the selected investigators.

The allocation of instruments and other payload elements to the EOS-A1 platform was made in February 1991. The confirmed payload set for the EOS-A1 platform includes the following instruments:

- AIRS/AMSU-A/MHS
- ASTER
- CERES
- EOSP
- HIRDLS
- LIS
- MIMR
- MISR
- MODIS-N/T
- MOPITT
- STIKSCAT.

This suite of instruments will focus on the physical climate system, including atmospheric structure and circulation, mass and surface processes, and the dynamics of terrestrial and marine ecosystems, which involves their coupling to the physical climate system and their influence upon the chemistry of the atmosphere, particularly the troposphere. The measurements from these instruments will focus on observations that provide information about fluxes at the Earth's surface or the coupling between the troposphere and the stratosphere. HIRIS, the High-Resolution Imaging Spectrometer, is scheduled to fly on the second and third platforms of the EOS-A series. Implicit in the selection of these instruments was the assumption that satellites and missions such as an ocean color instrument, UARS, TOPEX/Poseidon, and a follow-on to the Total Ozone Mapping Spectrometer (TOMS) would fly.

The configuration of EOS-B and the selection of suitable instruments will be made in mid-1992. The suite of instruments selected for EOS-B will extend the observational foci into the stratosphere, and will expand the set of measured chemical species in the troposphere. Furthermore, the selected instruments will provide additional important Earth surface information, such as ice sheet topography, tectonic deformations, and tropospheric winds.

The Mission Elements section provides more detail on both the EOS-A and -B platforms. ☆

International Cooperation

The Earth Observations International Coordination Working Group (EO-ICWG) is the forum within which the U.S., Europe, Japan, and Canada discuss, plan, and negotiate the international cooperation essential for implementation of an International Earth Observing System (IEOS) in the mid-late 1990s and beyond. The delegations to the EO-ICWG are led by the Earth observation offices of their respective space agencies: NASA, ESA, STA/NASDA/MITI, and CSA. The delegations also include respective operational environmental monitoring agencies: NOAA, EUMETSAT, JMA, and AES. The group meets three to four times per year, addressing a full range of technical and policy issues that include payload, operations, data management, data policy, and instrument interfaces. Based on the work of the EO-ICWG, the following elements are proposed as part of the IEOS: ESA's Polar Orbit Earth Observation Mission (POEM) series, beginning with POEM-1; the NASA Earth Observing System-A (EOS-A) series, beginning with EOS-A1; the NOAA Polar-Orbiting Environmental Satellites (POES), beginning with NOAA-N; the Japanese Advanced Earth Observing System (ADEOS); and the NASA/Japanese Tropical Rainfall Measuring Mission (TRMM). Refer to the Mission Elements section for a description of international contributions to the IEOS.

EUROPE

ESA is planning two series of polar-orbiting platforms—along with instrumentation, launch, operations, and the associated data system—as part of ESA's POEM mission. In addition, ESA will provide the Multiband Imaging Microwave Radio meter (MIMR) to fly on EOS-A as a facility instrument. EUMETSAT will provide the AMSU-MHS instrument for flight on EOS-A. AMSU-MHS will be provided for flight on the NOAA free-flyer and European operational payload as well. The research effort, the data exploitation aspects of the data system, and a number of the individual instruments included in POEM are national contributions from the individual member states of ESA. Furthermore, NASA has selected the HIRDLS instrument for EOS-A, which includes the Dynamics Limb Sounder (DLS) provided by the UK. France and the UK are sponsoring interdisciplinary investigations selected by NASA. The ESA POEM series will also carry the NASA CERES instrument to complement CERES flights on EOS-A and other missions.

The European contribution includes a cooperative effort between NOAA, EUMETSAT, and ESA to provide a European carrier and part of the payload for the operational meteorological suite of sensors that will fly in a morning equatorial crossing time orbit to complement the NOAA free-flying series, which cross in the afternoon.

JAPAN

The Japanese Earth observations program will support the international community beginning with the polar-orbiting ADEOS mission. This will be followed by a joint NASA/Japanese TRMM satellite that flies in a lower inclination orbit. Japan has proposed follow-on missions to both ADEOS and TRMM, to make up the Japanese Earth Observing System (JEOS). In the context of EO-ICWG, MITI is providing the ASTER instrument for flight on EOS-A. ADEOS will carry the NASA Scatterometer (NSCAT) and TOMS. TRMM will use a NASA-provided spacecraft, which will be boosted into orbit by a Japanese launch vehicle. The payload will be provided jointly by Japanese agencies and NASA. Japan is sponsoring one EOS interdisciplinary investigation as well.

CANADA

The Canadian Space Agency (CSA) has requested funding to provide the X band transmitter for direct downlink capability on the NASA EOS platforms. In addition, Canada will provide the MOPITT instrument, which will fly on EOS-A1, and is sponsoring two EOS interdisciplinary investigations.

OTHER

In addition to the above, EOS investigations were selected by NASA and are being funded by national agencies in Brazil and Australia. ☆

	KEY PROGRAM MILESTONES (CY)	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
01	**Instrument Confirmation**											
02	EOS-A	●										
03	EOS-B		●									
04	**EOS-B Platform Study**	●										
05	**EOSDIS Core System Contract**		●									
06	**EOSDIS Version 0 Implementation**				●							
07	**EOS-A1 Instrument Deliveries**							●				
08	**Launch Readiness**											
09	UARS	●										
10	EOS-A1								●			
11	EOS SAR										●	
12	EOS-B1											●
13	NOAA Free-Flyer											●
14	**Int'l Missions Launch Readiness**											
15	Advanced Earth Observation Satellite					●						
16	Tropical Rainfall Measuring Mission							●				
17	ESA POEM-1							●				
18	JEOS Polar								●			
19	JEOS 55° Inclination										●	
20	ESA EPOP-N1										●	

Role of the National Oceanic and Atmospheric Administration

NOAA's planned free-flying polar-orbiting satellites and the European polar platforms will carry the operational instrumentation required to carry out NOAA's mandate. The data from these sensors will provide important long-term continuity of observations for the Earth science research community. The NASA and ESA platforms will carry advanced versions of some operational instruments to demonstrate new techniques and to explore potential enhancements to operational service for the future. The data from these prototype operational instruments will be available to NOAA, EUMETSAT, and other organizations for real-time operational evaluation. NOAA will also serve as the long-term archivist for a major portion of the EOS data, and will continue to make available *in situ* data from its data centers. NOAA actively participates in the EO-ICWG and chairs the Interagency Working Group on Data Management for Global Change (IWGDMGC), where interagency data exchange arrangements and policies are planned and coordinated. ☆

Global Change Fellowship Program

The EOS budget contains a special fund earmarked for graduate students involved in Earth system science research. Fellowships are given for an initial 1-year term and may be renewed annually for up to 3 years, based on satisfactory progress as reflected in academic performance and evaluations made by faculty advisors. The amount of award for 1991 is $20,000, which may be used as a stipend to defray living expenses, tuition, travel, books and supplies, and fees. A further amount of $2,000 is available by request for the faculty advisor's use in support of the student's research. A total of 37 fellowships were conferred in 1990 (see Table 1), and up to 50 new fellowships will be awarded in 1991. The total number of grants will increase prior to the launch of the EOS observatories, thereby ensuring a pool of highly qualified Earth scientists to disseminate the data generated during the15-year design lifetime. Eventually, the Earth Science Fellowship Program will fund up to 150 graduate students per year for the duration of the mission; of course, the availability of funds dictates the final number of scholarships.

Candidates must be admitted to or already enrolled in full-time Ph.D. programs at accredited U.S. universities or other institutions of higher education. Students may also apply in their senior year prior to receiving their baccalaureate degree, but must be enrolled in a Ph.D. program at the time of award. Applications will be considered for research on climate and hydrologic systems, ecological systems and dynamics, biogeochemical dynamics, solid Earth processes, Earth system history, human interactions, data and information systems, and solar influences. Atmospheric chemistry and physics, ocean biology and physics, ecosystem dynamics, hydrology, cryospheric processes, geology, and geophysics are also acceptable areas of study, provided that the research topic is relevant to NASA's global change efforts—specifically, EOS and Mission to Planet Earth.

Petitions for a Global Change Fellowship entail a completed application form, a 3-page research proposal, copies of undergraduate and graduate transcripts (if applicable), and three letters of reference. Instructions for preparing the research proposal and the ancillary forms can be acquired by sending queries to:

NASA Global Change Fellowship Program
Code SE-44(GC)
NASA Headquarters
Washington, DC 20546

These graduate student fellowship information packets are available each January, and must be completed by April 1 to be considered for the following academic year. Five copies of the application form, proposal, and transcripts need to be forwarded as a package to the above address, and the letters of reference must be sent under separate cover. Of course, the applicant must ensure that the letters have been received by NASA prior to the established deadline. Incomplete packages and/or those received after the April 1 deadline are not considered in the selection process.

Applications are reviewed on a competitive basis through a two-step process. The first step involves a mail review, which weans out deficient proposals by assessing the calibre of student, quality of research, and relevance to the U.S. Global Change Research Program. Those applications that pass the initial screening are then evaluated by a panel composed of members of professional scientific societies, academic institutions, NASA Centers, and the Educational Affairs and Earth Science and Applications Divisions of NASA Headquarters. Results of the competition are announced by June 30th, with the anticipated starting date of awarded fellowships September 1st. Students receiving stipends must not receive other Federal funding, including monies from other Federal fellowships, traineeships, or employment.

Competition is quite fierce. Over 300 applications were submitted by interested students in CY 1990, and this overwhelming response resulted in a jump from the anticipated 25 to a total of 37 fellowship recipients, whose topics covered the whole spectrum of the Earth sciences. In all, 92 universities from 43 states were represented, and citizens from 32 countries participated. The 1990 class ended up representing 27 universities from 19 states and 11 different countries. U.S. citizens and resident aliens are given preference in the review process; however, this does not preclude foreign nationals who are pursuing their graduate studies in the U.S. from applying. No one shall be denied consideration or appointment on grounds of race, creed, color, national origin, age, or sex.

A student receiving support under the Global Change Fellowship Program does not incur any formal obligation to the Government of the United States; however, the objectives of this program will clearly be served best if the student is encouraged to actively pursue global change research after completion of graduate studies. By offering the opportunity to participate in this prestigious program, NASA hopes to attract the world's most outstanding scientists, both in the role of graduate fellows and faculty advisors. The ultimate goal is to increase the number of well-trained Earth scientists in the EOS era. ☆

Table 1 1990 Global Change Fellowship Recipients

GCC	Fellow	Country	Institution	Abbreviated Proposal Title
Biogeochemical Dynamics	David W. Bolgrien	U.S.	University of Wisconsin, Milwaukee	Satellite Limnology: Assessment of Water Quality of Large Lakes
	Anne M. Braunschweig	U.S.	University of Minnesota, Twin Cities	Modeling of Methane Production from Minnesota Peat Lands
	Margaret K.M. Brown	U.S.	University of Washington	Increases in Emissions of Methane and its Impact on Atmospheric Chem and Radiation
	Mary-Lynn Dickson	Canada	Oregon State University	Nitrogen Dynamics in the Upper Ocean: The Pelagic Foodweb Structure
	Stephen K. Hamilton	U.S.	University of California, Santa Barbara	Regional-Scale Hydro and Biogeochem Processes in the Brazilian Gran Pantanal Wetlands
	Jacqueline K. Holen	U.S.	Stanford University	The Hydrodynamics of Phytoplankton in an Estuarine System
	Ann P. Kinzig	U.S.	University of California, Berkeley	Effects of Global Warming on Trace Greenhouse Gas Fluxes
	Laura L. Landrum	U.S.	University of Washington	Modeling CO2 Uptake in the North Pacific
	Steven A. Lloyd	U.S.	Harvard University	Key Radiative, Chem, and Dynamical Processes Controlling Strat Ozone Abundance
	Lars L. Pierce	U.S.	University of Montana	Terrestrial Biogeochemical Cycles: Regional Evapotrans and Net Primary Production
	Young Sunwoo	Korea	University of Iowa	Trends in Surface, Tropospheric, and Total Ozone Abundance in the Pacific Rim Region
	Renyi Zhang	China	Massachusetts Institute of Technology	Heterogeneous Reaction Mechanisms of Polar Ozone Depletion
Climate and Hydrologic Systems	Afshan Alam	India	Pennsylvania State University	Thermodynamic Coupling Between the Atmosphere and Arctic Ocean
	Ana P. Barros	Portugal	University of Washington	The Role of the Alpine Cryosphere in Global Change Research
	Timothy M. Del Sole	U.S.	Harvard University	Numeric Simulation of Baroclinic Transport for Application to Poleward Heat Flux
	Maria C. Forbes	Argentina	University of Miami	Low Frequency Variability in the South Atlantic using GEOSAT Altimetric Data
	Marguerite Gerstell	U.S.	Harvard University	Investigate the Influence of Cloud Systems on the Runaway Greenhouse Effect
	Stephen A. Klein	U.S.	University of Washington	Clouds: Radiation and Large-Scale Dynamics
	Cecilie Mauritzen	Norway	Massachusetts Institute of Technology	Ocean Circulation in the Greenland and Norwegian Seas
	Joanna E. Muench	U.S.	University of Washington	Generation and Propagation of 21-Day Waves During the 1982/83 El Niño
	Jon T. Nelson	U.S.	University of Washington	Transformation of Precursor Gases to Aerosol Particles andGrowth into Cloud Droplets
	Vannaroth Nuth	U.S.	University of Texas, Austin	Global Ice Sheet and Mean Sea Level Changes Using Satellite Altimetry
	Scott D. Peckham	U.S.	University of Colorado, Boulder	Scaling and Multi-scaling of Hydrologic Processes with the Aid of Remote Sensing
	Thomas C. Peterson	U.S.	Colorado State University	Surface Warming, Clouds, Water Vapor, and Radiative Effects
	Eric P. Salathe	U.S.	Yale University	Upper Level Water Vapor and Atmospheric Radiation
	Brian J. Soden	U.S.	University of Chicago	The Role of Cloud Radiative Forcing Feedback Mechanisms in Earth's Climate
	Richard W. Turner	U.S.	Iowa State University	Changes in Soil-Moisture Level and Distribution on Regional-Scale Circulations
	Susan E. Wifjjels	Australia	Woods Hole Oceanographic Institute	The Role of the Tropical Pacific in the Global Heat and Freshwater Balances
	Randolph H. Wynne	U.S.	University of Wisconsin, Madison	Lakes as Indicators of Global Change
	Edward D. Zaron	U.S.	Oregon State University	An Investigation of the North Pacific
DIS	James W. Hardin	U.S.	Texas A&M University	Detectability of Global Change with Discrete Global Observing Systems
Eco-system Dynamics	Tracy L. Benning	U.S.	Kansas State University	Retrospective Analysis of Productivity in Response to Climatic Variations
	William M. Childress	U.S.	Texas A&M University	Cellular Automata: Linking Large and Small-Scale Spatial Processes in Ecology
	John F. Weishampel	U.S.	University of Virginia	Interfacing Satellite-Based Microwave Data to Dynamic Tropical Rainforest Models
SI	Carter L. Grotbeck	U.S.	University of Arizona	Solar Aureole Instrumentation and Inversion Techniques for Aerosol Studies
Solid Earth	Andrea Szilagyi	Hungary	Purdue University	Relationships between Salinity and Spectral Reflectance of Soils
	Thorvaldu Thodarson	Iceland	University of Hawaii, Manoa	Basaltic Fissure Eruptions and their Impact on the Earth's Atmosphere

KEY: DIS = Data and Information Systems GGC = Global Change Category SI = Solar Influences

Management of EOS

Overall responsibility within NASA for the EOS mission is assigned to the Office of Space Science and Applications (OSSA) at NASA Headquarters. Lead responsibility for the implementation of EOS is assigned to Goddard Space Flight Center.

The Program Office for EOS within OSSA is the Earth Science and Applications Division (ESAD), which is responsible for all aspects of NASA's contribution to the Global Change Research Program. Almost all of the work of this Division is focused on the study of global change. Due to the size, significance, and differences in management strategies of the component elements of the program, the Division has been divided into four Program Offices. The responsibilities for elements of EOS are assigned to three of these offices, as indicated by the shaded portions of Figure 4. The EOS Program Office has responsibility for the spacecraft, the physical integration and test of the space systems, and the Program-level integration and technical assessment of all elements. Continuity with existing efforts involving instrument development has led to the assignment of the instrument development segment of EOS to the Flight Systems and Instrument Development Program Office. The data system and science are managed by the Modeling, Data, and Information Systems Program Office, serving to insulate EOSDIS to the extent possible from traditional tendencies to compromise the data system in pursuit of space hardware development. This also recognizes that EOSDIS will serve as the Earth science and applications discipline data system within NASA, a function that goes beyond EOS to serve all of NASA's global change research activities.

Scientific integration and oversight of EOS is provided through a Program Scientist function. For EOS, this role is carried out by a full-time Mission to Planet Earth Program Scientist who reports directly to the Earth Science and Applications Division Director. The Program Scientist is supported by a dedicated staff of two assistants. Integration of EOS science with the overall research program of the Division is facilitated by assigning the role of EOS Element Program Scientist to various research managers within the Division. Virtually all research managers in ESAD assume such a responsibility, and each investigation and major element of EOSDIS has such an element program scientist appointed.

GSFC has also reorganized to better accomplish its EOS responsibilities. Key features of the GSFC structure are the elevation of the EOS Project Manager to the level of Deputy Director of Flight Projects; the formation of three EOS Project Offices to handle the EOSDIS, EOS payloads, and EOS observatories, including the polar platforms; and the establishment of the Project Scientist as a member of the staff of the Director of Earth Science. The Systems Management Office will provide the necessary integration across all of the individual projects. See Figure 5 for a schematic of the EOS Project management hierarchy. ☆

Figure 4 NASA Headquarters Earth Science and Applications Division

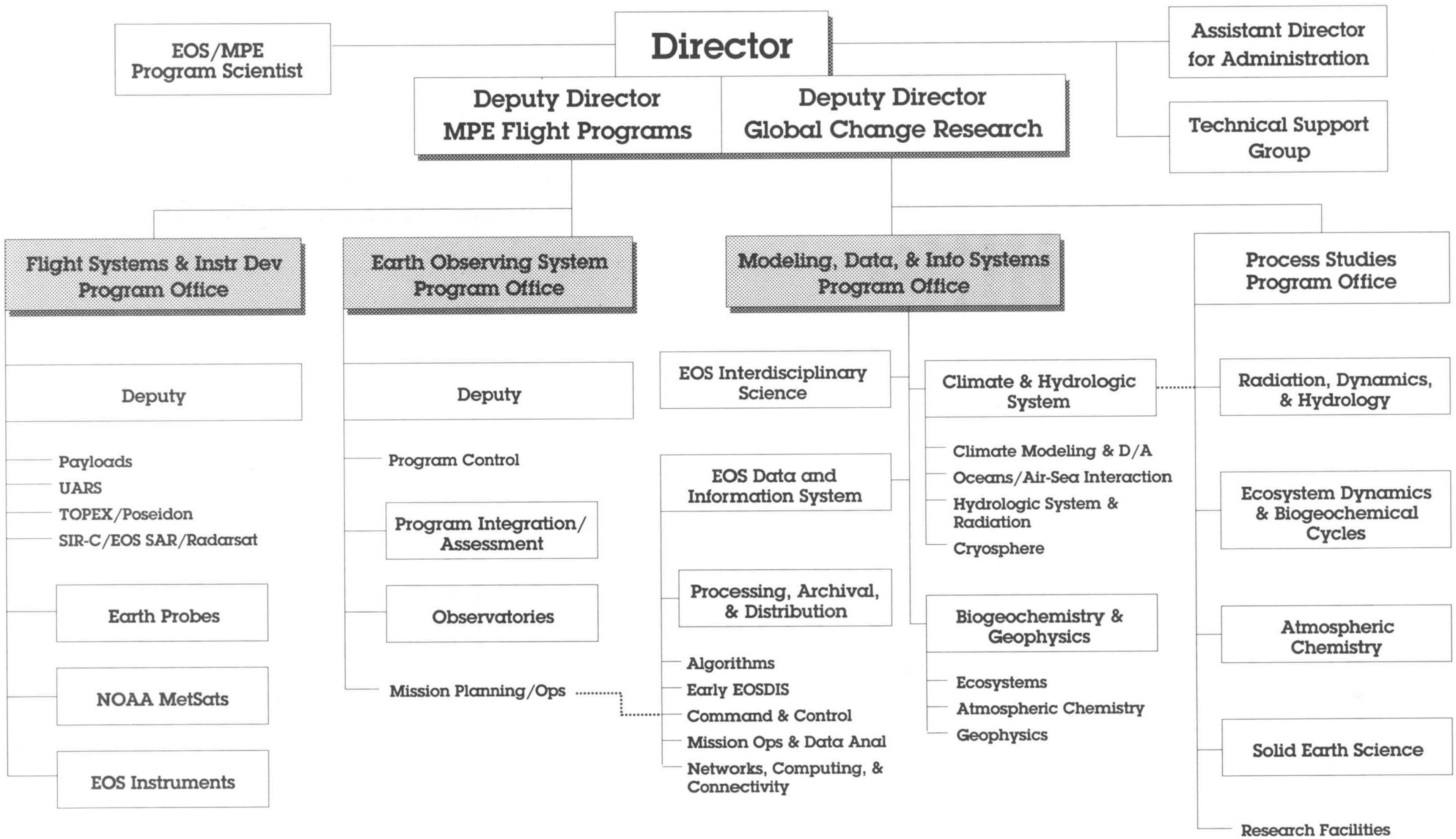


Figure 5 The EOS Project Office

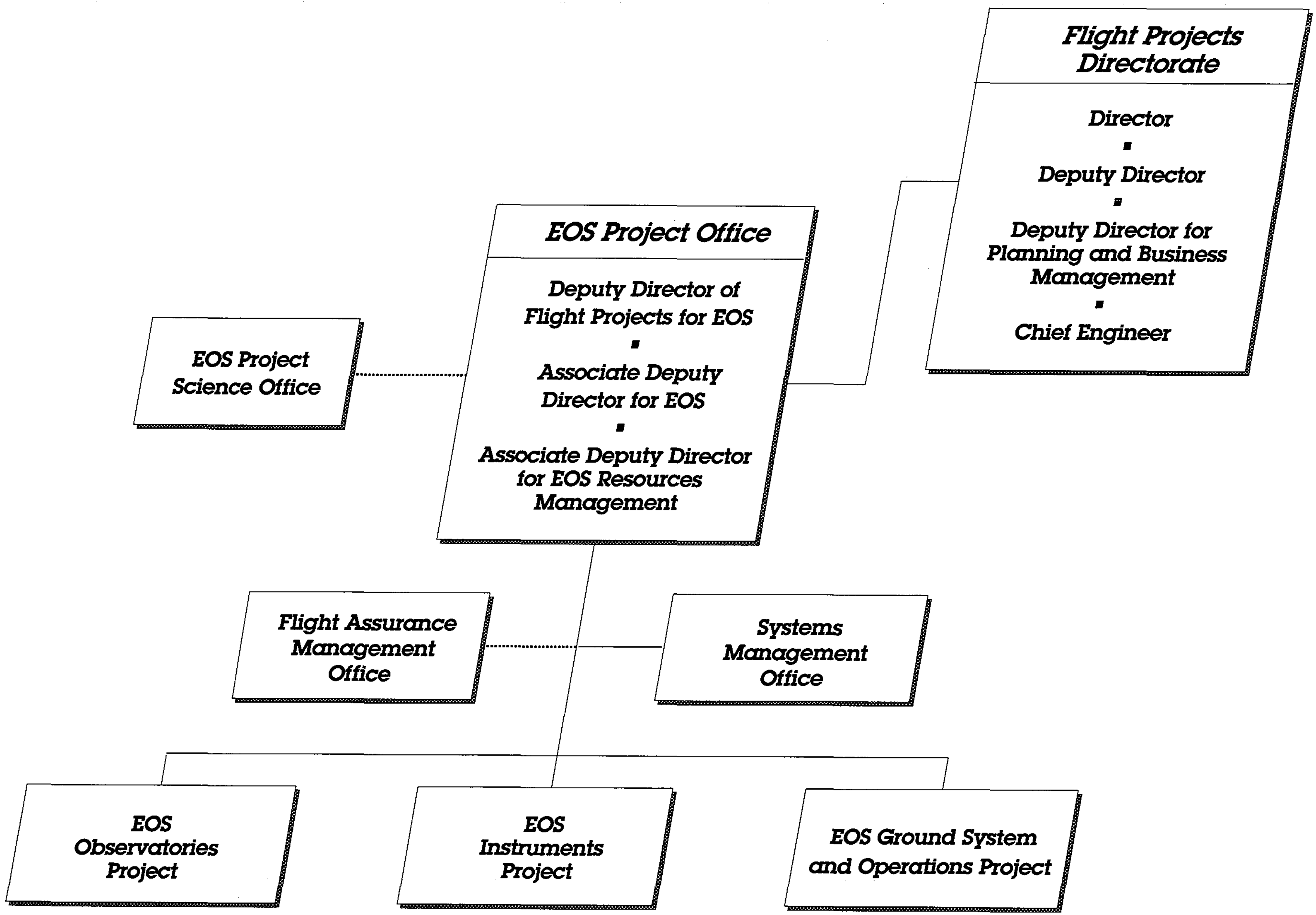


Table 2 Proposed Instrument Configuration

OBJECTIVES	PROPOSED INSTRUMENT CONFIGURATION									
	ADEOS 799.8 km 10:30 a.m. 1Q 1995	*TRMM 350 km 35° Inclination 1Q 1997*	*ESA POEM-1 790 km 10:00 am 3Q 1997*	*JEOS Polar 1Q 1998*	*NASA EOS-A Series 705 km 1:30 pm 4Q 1998*	*ESA EPOP-N1 1999*	*NASA EOS SAR 620 km 1:30 pm 2000*	*JEOS 55° Inclination 2000*	*Post-NOAA-N 824 km 1:30 pm 2Q 2001*	*NASA EOS-B Series 705 km 2Q 2001***
VIS/IR Images	OCTS, AVNIR, POLDER	VIRS, LIS	MERIS, AVHRR-4	GLI, IMB'	MODIS-N/T, LIS, ASTER, MISR, EOSP, HIRIS*	HRDI		VIS/IR Imager, LIS	VIS/IR Imager	MODIS-N, HIRIS
Radiation Budget		CERES (1)	CERES (1), AATSR		CERES (2)			CERES (2)		
Passive Atmospheric Sounding			AMSU-MTS/MHS, HIRS-4, IASI	AMSR***	AIRS, AMSU			AMSR***	IR Sounder, MTS, MHS	
Passive Microwave		TMI		AMSR	MIMR			AMSR		
Active Microwave	NSCAT	PR	A-SCAT	(D)PR	STIKSCAT	A-SAR	SAR	(D)PR		
Tropospheric Chemistry	IMG		SCIAMACHY, IASI	TERSE, ISTG	MOPITT					TES, MOPITT
Stratospheric Chemistry	TOMS, ILAS		GOMOS, MIPAS, SCIAMACHY	TOMUIS, SLIES, ISTG	HIRDLS			SAGE III, ILAS	Ozone Monitor, SBUV	SAFIRE, MLS, SWIRLS, HIRDLS, SAGE III
Tropospheric Wind Lidar										LAWS
Altimeter			RA-2, PRAREE	ADALT'						ALT
Laser Ranging and Sounder				E-LIDAR		ATLID				GLRS
Other	RIS		MCP, ARGOS+		COMM PKG, WBDCS, ACRIM	APAFO, AURIO			Data Collection System, COMM PKG	GGI, COMM PKG, IPEI, GOS, XIE, SOLSTICE II
Operational Instruments			AVHRR-4, AMSU-MTS/MHS, SEM, S&R, HIRS-4, ARGOS+, MCP						VIS/IR Imager, IR Sounder, MTS, MHS, Ozone Monitor, SEM, SARSAT, Data Collection System	

5/91

*Second and third EOS-A platforms only.
**A single spacecraft cannot accommodate the full set of instrument candidates.
***Assumes AMSR includes sounding channels at 55 GHz.

Mission Elements

EOS-A

The primary goal of the EOS-A series is to provide a suite of measurements that yields information on global warming and other critical aspects of global change, including the Earth's radiation balance, atmospheric circulation, air-sea interaction, biological productivity, and land-surface properties. Quantitatively intercomparable measurements of given variables will enhance the observational continuity of the EOS-A series. Simultaneous measurement by the selected instruments proves critical in satisfying the science requirements posed for the EOS-A series. The scientific objectives of most of the EOS-A instruments can only be met by co-location on the same spacecraft, thereby observing phenomena through the same column of air, at different resolutions and in different spectral regions, at essentially the same time. To allow co-location of the selected instruments, single large observatories will make up the EOS-A series. Each of the three observatories will be functionally identical, commensurate with its instrument payload, and will have a 5-year design life, resulting in a 15-year global data set.

The EOS-A observatories are scheduled to be launched aboard Titan IV launch vehicles from the Western Space and Missile Center, beginning in 1998. The observatories will be inserted into 705-km, 16-day, 233-orbit repeat sun-synchronous orbits with a 1:30 p.m. ascending nodal crossing time. The observatory design will support an instrument payload with a mass of 3,500 kg, an average power of 3.2 kW (4.2 kW peak), and an average data rate of 30 Mbps (300 Mbps peak), and that produces up to 1 Terabit of data over two consecutive orbits. Observatory command and control will be through the TDRSS. The design will also support direct-to-ground instrument data transmission rates of up to 15 Mbps continuous broadcast and 100 Mbps intermittent broadcast (for up to two Earth contacts per orbit). Although serviceability is not planned, the EOS-A series observatory design will allow robotic servicing. Figure 6 provides a line drawing of the observatory design.

The 14 instruments that NASA has selected for flight on the first EOS-A observatory, as well as for tentative flight on the second and third observatories, are AIRS/AMSU-A/MHS, ASTER, CERES, EOSP, HIRDLS (selected for the first observatory), LIS, MIMR (pending resolution of technical issues), MISR, MODIS-N/T, MOPITT (provided for the first observatory), and STIKSCAT. HIRIS has been tentatively selected for flight on the second and third observatories. In addition to flight on EOS-A, CERES and LIS were originally planned for flight attached to Space Station *Freedom* beginning in 1998. However, Space Station *Freedom* restructuring has removed much of the required accommodation interfaces, so NASA will consider CERES and LIS for additional flights of opportunity.

Twelve of the 16 instruments selected for flight on the EOS-A series constitute a minimum set of synergistic instruments for making simultaneous observations. Refer to the EOS Observatories section for a discussion of simultaneity requirements.

In addition to the synergistic instrument set, HIRDLS will extend the monitoring of important stratospheric chemical constituents beyond the planned lifetime of the UARS, which is scheduled for launch in late 1991; LIS will monitor the rate, position, and radiant energy of lightning flashes; and MOPITT will monitor carbon monoxide and methane in the lower atmosphere.

Detailed descriptions of the A series instruments are contained in the EOS Instruments section. The EOS-A series will also include a Direct Broadcast system, a Direct Downlink system, and a Wide-Band Data Collection System (WBDCS). The Canadians have offered to provide the Direct Broadcast and Downlink systems. While all EOS data will be downlinked via TDRSS to EOSDIS, the Direct Broadcast and Downlink systems will support transmission to ground stations of EOS users around the world who require direct data reception. These users fall into at least three classes:

- EOS team participants and interdisciplinary scientists who require real-time data to conduct or validate field observations, to plan aircraft campaigns, or to observe rapidly changing conditions in the field

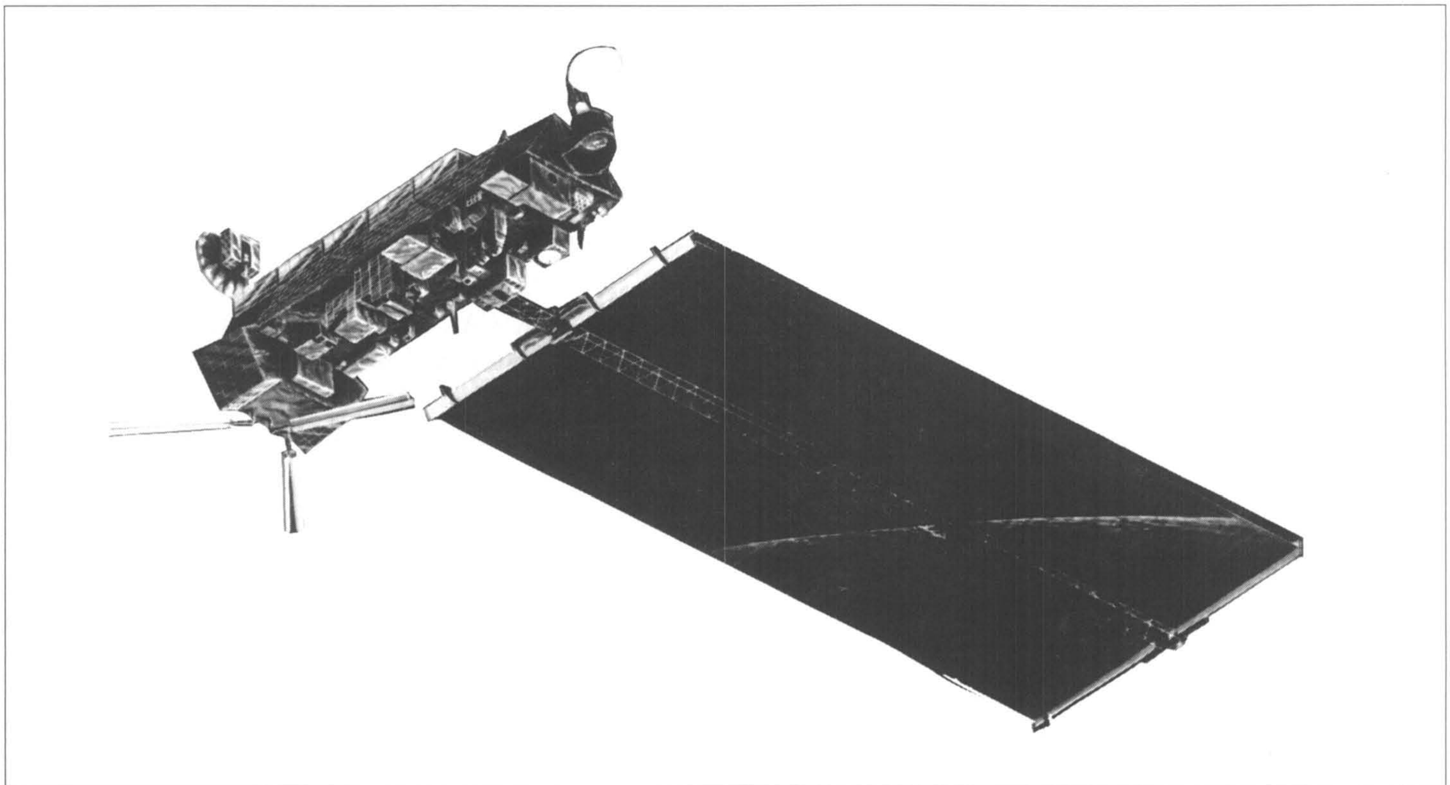


Figure 6. The EOS-A Observatory

- International meteorological and environmental agencies that require real-time measurements of the atmosphere, storm and flood status, water temperature, and vegetation stress

- International Partners who require receipt of data from their high data volume EOS instruments at their own analysis centers for engineering quality checks and scientific studies.

The Direct Broadcast system will transmit continuously at a rate of 15 Mbps all data from AIRS/AMSU-A/MHS, STIKSCAT, MIMR, and MODIS-N. At this data rate, relatively low-cost ground stations can receive, process, and display the swath data as the satellite passes within the range of each Earth-based antenna. Several countries have expressed interest in the Direct Broadcast system, or have developed similar ground station capabilities in the past, including Australia, Italy, Japan, Taiwan, Canada, the Philippines, Indonesia, Thailand, New Zealand, and Brazil. Bangladesh and Fiji have requested aid to develop the technology for real-time monitoring of resources and disasters.

The Direct Downlink system will support intermittent transmissions at 115 Mbps to serve International Partners who require high data rate transmissions directly from EOS. ASTER and HIRIS will use this capability. Because of the large ground antennae and high-volume data processing equipment required, reception of transmissions at 115 Mbps will be via X band facilities similar to existing Landsat or SPOT ground stations. The Direct Broadcast system can also serve as a backup if the TDRSS link fails.

WBDCS consists of two elements: A space segment mounted on the EOS spacecraft and a ground segment installed at a network of ground stations. WBDCS will record global *in situ* data collected by a network of 128 ground stations operated by the Incorporated Research Institutions of Seismology (IRIS). These ground stations are nominally separated by 2,000 km, and primarily monitor seismic events for tomographic mapping of the Earth's interior, earthquake prediction and warning, and epicenter location. In addition, some of the Antarctic stations will also provide measurements of Antarctic ultraviolet levels, atmospheric chemistry, and other science data. WBDCS receives data transmitted from the ground at a data rate of 2 Mbps at 7.195 GHz. The space segment broadcasts commands at a data rate of 2 kbps at 8.456 GHz. The average system data rate is 512 kbps. Each IRIS ground station may transmit up to 256 Mb of data per day. Data collected by WBDCS is then transmitted to EOSDIS with the other science data via TDRSS.

EOS-B

The EOS-B series will provide a suite of measurements related to potential global warming and other critical aspects of global change that are complementary to those provided by EOS-A. The EOS-B series will conduct an expanded study of stratospheric ozone, obtaining complete coverage of chemical species and winds, continuing the measurements obtained by HIRDLS on the first EOS-A observatory, and establishing a much longer data record than the 1.5-year UARS mission, which is scheduled for launch in late 1991. EOS-B will also achieve the first global monitoring of tropospheric chemistry. It will observe ocean circulation and make air-sea interaction measurements as a follow-on to TOPEX/Poseidon and NSCAT on ADEOS, and will study earthquakes and growth/mass balance of ice sheets. As with the EOS-A series, all measurements of given variables will be quantitatively intercomparable to enhance observational continuity.

The baseline design calls for observatories in the EOS-B series to be identical to those in the EOS-A series, with exceptions made to accommodate the different instrument complement. The scientific need for simultaneous measurements by the instruments selected for flight on the EOS-A series is critical; however, the case is not as compelling for the EOS-B series. Candidate EOS-B instruments could potentially be subdivided into smaller scientific clusters such as surface topography, atmospheric chemistry, surface imaging, atmospheric winds, particles and fields, and solar luminosity, thereby compatible with smaller spacecraft and launch vehicles. To ensure the most effective approach, NASA has delayed the confirmation of EOS-B instruments until late 1992, and is presently reviewing optional spacecraft configurations that would satisfy the science requirements of the EOS-B series and its instrument candidates.

Regardless of the number of observatories that carry the instruments selected for the EOS-B series, there will be three functionally identical copies of each one, commensurate with the applicable instrument payload. Each observatory will have a 5-year design life, resulting in a 15-year global data set. Observatory command and control will be through TDRSS. Launch(es) of the EOS-B observatories are scheduled to begin 2.5 years after the first EOS-A series observatory.

The instrument candidates for flight on the EOS-B series observatories are:

- Surface Topography: ALT, GGI, and GLRS
- Atmospheric Chemistry: HIRDLS, MLS, MOPITT, SAFIRE, SAGE III, SWIRLS, and TES
- Surface Imaging: HIRIS and MODIS-N
- Atmospheric Winds: LAWS and SWIRLS
- Particles and Fields: GOS, IPEI, and XIE
- Solar Luminosity: SOLSTICE II.

An additional copy of SAGE III was originally planned for flight attached to Space Station *Freedom* beginning in 1998. However, Space Station *Freedom* restructuring has removed much of its required accommodation interface, so NASA will consider SAGE III for an additional flight of opportunity.

Detailed descriptions of the B series instruments are contained in the EOS Instruments section. Four of the EOS-B candidates have also been selected for flight on EOS-A: HIRDLS, MOPITT, HIRIS, and MODIS-N. HIRDLS, MOPITT, and HIRIS will fly on only one observatory series. The second and third EOS-A platforms can accommodate either HIRIS or both HIRDLS and MOPITT, but not all three instruments. If HIRIS is confirmed for the second and third EOS-A observatories, it will no longer be a candidate for EOS-B, but HIRDLS and MOPITT will be candidates. Alternatively, if HIRDLS and MOPITT continue to fly on EOS-A, they will not beEOS-B candidates, but HIRIS will be a candidate.MODIS-N is being considered for flight on EOS-B inaddition to its flight on EOS-A, in order to provide a robust backup capability.

There are several science requirements inherent in the instrument candidate set that must be met by any EOS-B spacecraft configuration. There are three co-location requirements, which dictate that pairs of instruments always be flown on the same spacecraft. ALT and GLRS require precise knowledge of spacecraft location, which GGI provides; so ALT and GLRS must each be co-located with GGI. MODIS-N and HIRIS must be co-located to allow cross-calibration and simultaneity of observations.

In addition to the co-location requirements, flying some instruments together will enhance their scientific return. Specifically, flight of HIRDLS (if it is flown on EOS-B), MLS, SAFIRE, SWIRLS, and TES together would guarantee that they all observe roughly the same areas of the stratosphere at the same time, thereby enhancing the science return.

Because many of the EOS-B instrument candidates do not have strict grouping requirements, they could be deployed on multiple spacecraft that could place them in different orbits to maximize the value of their data and provide the greatest science return. A 705-km orbit is acceptable for all instrument candidates; however, the science community currently believes that the following orbits would provide the greatest science return:

- ALT and GGI: 2:00 p.m. to 4:00 p.m. to complement POEM RA; 705-1,200 km to reduce drag with ±1 km repeat ground track
- GLRS and GGI: 9:00 a.m. to 11:00 a.m. for minimum clouds; up to 705 km
- Backup MODIS-N with HIRIS: 10:30 a.m. to complement EOS-A p.m. coverage; 705 km
- HIRDLS, MLS, SAFIRE, and SWIRLS: Noon to 2:00 p.m. for radical chemistry; 540-850 km
- TES: 11:00 a.m. to 1:00 p.m. for thermal contrast; up to 850 km
- SAGE III: 55° inclination for low- and mid-latitude occultations; up to 1,200 km
- LAWS: Either 55° or sun-synchronous inclination at any crossing time for tropical wind sampling; up to 705 km
- SAGE III: 10:00 a.m. to 2:00 p.m. for polar occultations; up to 1,200 km
- MOPITT: 10:00 a.m./800 km (or 1:30 p.m./705 km) to coincide roughly with temperature soundings
- GOS: Polar orbit between 80° and sun-synchronous inclination for complete global coverage; 600-850 km
- IPEI and XIE: Polar orbit between 80° and sun-synchronous inclination for auroral zone coverage; 600-850 km
- SOLSTICE II: Any orbit providing solar and stellar viewing.

While the process of determining optimal instrument clusters and spacecraft configurations will define the exact consequences of pursuing any individual option, smaller spacecraft configurations would not necessarily have a significant impact on EOS-B science requirements. The use of smaller spacecraft would still involve flight of the full complement of EOS-B instruments as would have been accommodated on one large spacecraft. However, it should be noted that the programmatic requirements related to the development, operation, and data integration of a larger number of spacecraft could increase both the program cost and complexity.

EOS SYNTHETIC APERTURE RADAR (EOS SAR)

The SAR instrument will be flown on a Delta-launched dedicated spacecraft because of its unique requirements. EOS SAR will monitor global deforestation and its impact on greenhouse gases; soil, snow, canopy moisture, and flood inundation, and their relationship to the global hydrologic cycle; and sea ice properties and their effect on polar heat flux. The SAR observatory has a 5-year design lifetime. As with the EOS-A and -B series, the SAR observatory will be replaced twice to achieve a 15-year mission duration. The observatory will be inserted into a 620-km, sun-synchronous orbit with an afternoon equator crossing time. A more detailed description of the SAR instrument can be found in the EOS Instruments section.

POLAR-ORBIT EARTH OBSERVATION MISSION (POEM)

POEM will make comprehensive research and operational observations of the Earth. ESA plans to have two series of observatories in the POEM program—the M series and the N series—but plans are still being finalized. Plans for the M series call for a focus on environmental monitoring, including global change and operational meteorology. The N series is expected to perform resource monitoring of land surface properties, and to study atmospheric chemistry and aerosol distribution. The first POEM mission will be in the M series, and is alternately called POEM-1 and EPOP-M1.

The POEM observatories will use ESA's polar platform modular bus, a design based on the SPOT-4 bus. Polar platform capabilities will include a payload mass of up to 2,400 kg, average power of 2.1 kW in sunlight and 1.9 kW in eclipse, up to six 50/100 Mbps channels (three direct-to-ground and three through DRS), and data storage capacity of 100 Gigabits. It is expected that POEM-1 will be launched from an Ariane 5 in late 1997 to a 700- to 850-km polar orbit with a 9:30 to 10:30 a.m. descending node. Plans call for POEM-1 to have a 4-year lifetime, with possible extension to 6 years. POEM-1 will not be serviceable.

The goal of long-term data continuity will be met through provision of several POEM platforms and through international cooperation. An alternate configuration with a reduced payload complement compatible with an Ariane 4 launch is being considered to ensure continuity of operational meteorological observations. The current baseline for the POEM-1 Phase B study includes:

- **Operational Meteorological Package**: AMSU-MTS/MHS (AMSU-A/B), ARGOS+, AVHRR-4, HIRS-4, MCP, S&R, and SEM
- **Facility Instruments**: A-SAR, A-SCAT, MERIS, MIPAS, and RA-2
- **Announcement of Opportunity (AO) Instruments**: Earth observation instruments (AATSR, CERES, GOMOS, PRAREE, and SCIAMACHY) and space science instruments (AURIO and APAFO).

The operational meteorological package flown on POEM-1 will replace NOAA's morning satellite series, with operational packages on follow-on ESA missions ensuring continuity of the series.

A-SCAT, RA-2, MERIS, and AATSR establish a unique observation and measurement complement for the biophysical characterization of oceans and coastal zones (>70% of the Earth's surface), thus giving an important key to climate and global environmental monitoring.

Together, MIPAS, GOMOS, and SCIAMACHY comprehensively monitor greenhouse gases, thereby studying global warming, ozone depletion, and climatic influence. Together with the operational meteorological package and CERES, they provide a tool to characterize both the lower and upper atmosphere, in view of its dynamics, radiative transfer, interactions, and the weather.

RA-2 and PRAREE must be flown on the same platform.

Operational Meteorological Package

The operational meteorological package will make operational weather observations on a high-frequency and regular basis. It is synergistic with all other instruments and will facilitate calibration of other instruments for atmospheric influence (e.g., MERIS and AATSR). The operational package will maintain the data continuity of the TIROS series (morning orbit).

- **AMSU-MTS/MHS** (AMSU-A/B) will generate global temperature profile, water vapor, precipitation, sea ice, snow cover, and ocean wind stress data. The passive microwave radiometer scans ±49.5° from nadir. Twenty-one channels are slated for MTS and five for MHS.
- **ARGOS+** relays messages from data collection platforms at 401.0 and 136.77 MHz.

- **AVHRR-4** will provide global monitoring of clouds, sea surface temperature, vegetation, and ice. It has a swath width of 2,200 km, 1-km resolution at nadir, and seven spectral bands, honing in on visible and infrared calibration targets.

- **HIRS-4** will provide global atmospheric temperature profiles, atmospheric water content, cloud properties, and Earth radiation budget data. It is a scanning radiometer, with 20 channels from 0.2 to 15 µm, a swath width of 2,250 km, and 21-km resolution at nadir. The instrument is provided by NOAA, and is based on proven technology (i.e., HIRS-3 heritage).

- **MCP** will provide direct data handling and broadcast of operational instrument data streams to ground stations.

- **S&R** will monitor distress signals at 406.05 + 0.04 MHz.

- **SEM** will monitor particles and fields to measure and predict solar events.

Facility Instruments

- **A-SAR** will provide all-weather imaging, at various resolution scales, of land surfaces, coastal zones, sea ice, and ice- and snow-covered surfaces. The instrument will measure parameters related to biomass, vegetation cover, hydrology, geology, soil conditions and soil moisture, land use, ice cover and ice dynamics, and coastal processes. It employs active antenna technology in three operational modes: Wide Swath/Scan SAR (wide swath with reduced spatial resolution), Image (high-resolution steered beam), and Wave (sampled imaging mode with low data rate over ocean). A-SAR has a 30-m resolution and operates at 5.3 GHz.

- **A-SCAT** will measure air-sea interaction/heat exchange, and ocean circulation and dynamics. The instrument is accurate to 2 m/sec (direction to 20°); provides 50 x 50 km resolution (unit cell), with possible enhancement to 25 x 25 km; and has a double swath (2 x 500 km) capability. It operates at 5.3 GHz. A-SCAT is synergistic with RA-2, MERIS, and AATSR for biophysical characterization of the ocean, ocean dynamics, and energy exchange. High-frequency observations are necessary to improve temporal and spatial sampling. A-SCAT ensures continuity with ERS-1/2 data products.

- **MERIS** will measure ocean color and biological components of the ocean, lending insight into the ocean's contribution to the carbon cycle. It provides high spectral resolution (5-20 nm) measurements in up to 15 selectable channels from 400 to 1,050 nm. Channel selection is programmable in orbit; channels are composites of solar spectrum measured over adjacent CCD detectors. About 600 CCD detectors are available in the spectral dimension, and up to about one-third of these can be sampled. Swath width is 1,500 km; spatial resolution is programmable to 250 x 250 m and 1000 x 1000 m (±20° along-track tilt). MERIS is synergistic with RA-2, A-SCAT, and AATSR, and proves unique in its capability to accurately detect organic matter.

- **MIPAS** is a limb sounder that will measure the composition, dynamics, and radiation balance of the middle and upper troposphere (i.e., atmospheric chemistry, ozone mapping, and monitoring of the greenhouse effect/global warming). It has a height range of 8 to 100 km, and 3-km vertical/30-km horizontal resolution. Its very high-resolution (0.025 nm), rapid-scanning capability permits retrieval of H_2O, O_3, CH_4, N_2O, F_{11}, F_{12}, F_{22}, CC_{14}, CF_4, NO, NO_2,ClO, H_2O_2, N_2O_5, HOCl, HNO_3, OCS, C_2H_2, C_2H_6, NH_3, and temperature. Sensitivity ranges from 4.5 to 15 µm in four spectral bands. MIPAS is synergistic with GOMOS and SCIAMACHY for complementary measurements (i.e., 3-D temperature field, aerosol loading, polar stratospheric cloud detection, and atmospheric chemistry). Its unique measurement combination and high observation frequency proves beneficial for global climate modeling.

- **RA-2** will provide significant wave height and sea level determination, ocean circulation (dynamics), ice sheet topography, and land mapping data. This adaptive pulse-limited radar altimeter possesses a transmit center frequency of 13.8 GHz, and an optional 3.2 GHz transmit frequency to measure and correct for ionospheric delays. An adaptive range window resolution (with bandwidth up to 330 MHz) is used for automatic gain control. RA-2 is synergistic with A-SCAT, MERIS, and AATSR, and proves unique for ocean currents, sea level rise, and ice sheet topography information; high frequency of observation improves temporal and spatial sampling. RA-2 requires the presence of PRAREE. As with A-SCAT and AATSR, RA-2 ensures continuity with ERS-1/2 data products.

AO Instruments (Earth Observations)

- **AATSR** will provide high-precision sea surface temperature retrieval and land-surface bidirectional measurements for ocean dynamics and radiation interaction studies. This imaging radiometer has 10 channels (bandwidth) in nm [470 (20), 550 (20), 670 (20), 870 (20), 1240 (20), 1610 (60), 3750 (400), 4000 (TBD)] and in µm [10.85 (1.0), 12.00 (1.0)]. Signal-to-noise ratio equals 20 for the visible/near-infrared channels; 800 at 270K for the 12.0 and 10.85 µm channels; and 227 at 270 K for the 3.75 channel. It has a 500-km swath width, and a 500-m field-of-view (FOV) at nadir for channels up to 1.6 µm and a 1-km FOV for channels beyond 1.6 µm. It possesses two viewing angles: Nadir and 47° forward from nadir. AATSR is synergistic with RA-2, A-SCAT, and MERIS, and provides continuity with ERS-1/2 data products.

- **CERES** will provide long-term monitoring of "top of the atmosphere" global radiation flux with a high degree of calibration stability. Consequent Earth radiation budget and atmospheric radiation measurements will further understanding of the climate system and atmospheric energetics, helping define the role of clouds in atmospheric dynamics. CERES' single broadband scanning radiometer is based on ERBE instrument heritage. CERES monitors radiation in three bands (0.3-3.5 µm, 8-12 µm, 5.0->50.0 µm), and detects reflected and emitted thermal radiation to 5 W/m^2. Along-track scanning of ±76° provides global overlapping coverage. Field-of-view at nadir is approximately 25 km. CERES has a calibration accuracy of better than 1% in longwave and 2% in shortwave bands, and stability of better than 0.5% over 5 years. High observation frequency is necessary, as is temporal interpolation (diurnal cycle).

- **GOMOS** will monitor global ozone, enhancing knowledge of ozone depletion and its impact on the greenhouse effect. The instrument provides stable reference data on global ozone, plus observations of H_2O, NO_2, NO_3, ClO, BrO, OClO, temperature (O_2), and aerosols through the use of two bore-sighted telescopes, each with its own grating spectrometer. Spectrometer A covers the spectral ranges of 250-450 nm and 425-650 nm (0.6-nm resolution); spectrometer B covers the ranges of 758-772 nm and 926-943 nm (0.07-nm resolution). About 25 stars can be monitored by occultation, each up to 14 times per day. Nadir solar backscatter ultraviolet measurements are also possible. The limb-viewing mode operates over a vertical range of approximately 20 to 100 km, and has a vertical resolution of approximately 2 km. GOMOS is synergistic with MIPAS and SCIAMACHY.

- **PRAREE** will provide high-precision orbitography, geodesy, plate tectonics, and ocean topography data. This instrument refines satellite position to within millimeters, studies plate motion, and monitors seismic deformation through the use of a two-way, three-frequency (X, S, and UHF bands) tracking system, complemented by laser corrections. PRAREE will operate with at least 20 ground stations. PRAREE complements RA-2.

- **SCIAMACHY** will measure the total concentration distribution of atmospheric trace gas species in the troposphere and stratosphere. By detecting atmospheric pollutants, researchers will further understanding of the interactions between atmospheric layers and how they affect the global climate system. This instrument will retrieve the vertical distribution of numerous atmospheric species, monitoring tropospheric and/or stratospheric chemistry for H_2O, O_3, CH_4, N_2O, NO, NO_2, NO_3, ClO, SO_2, BrO, OClO, HCHO, CO, CO_2, temperature (O_2 and CO_2 bands), and aerosols. Two identical optical paths are capable of viewing in limb-scanning (including occultation) or nadir modes, using array detectors and grating spectrometers in the following spectral ranges: 240-295 nm (0.11 nm bands), 290-405 nm (0.12 nm), 400-700 nm (0.15 nm), 650-1050 nm (0.20 nm), 940-1,350 nm (0.20 nm), 1,980-2,020 nm (0.08 nm), and 2,250-2,390 nm (0.09 nm). Signal-to-noise ratio can be up to 5,000 in the ultraviolet/visible and 500 in the infrared. SCIAMACHY possesses a vertical resolution of 1 km from 20-100 km in limb-sounding mode (3-km retrievals expected); scans ±40° in nadir-viewing mode; and has a 0.25 x 25.0 km field-of-view at nadir. SCIAMACHY is synergistic with MIPAS and GOMOS.

AO Instruments (Space Science)

- **APAFO** will be composed of the GOS magnetometer, plus IPEI, the XIE particle detector, and other particle detectors. This instrument must be flown with AURIO.

- **AURIO** will provide high spatial/temporal resolution images of the aurora at x-ray, ultraviolet, visible, and infrared wavelengths. Flown on the same low-altitude platform, APAFO and AURIO will provide important, unique measurements for the study of a variety of solar-terrestrial phenomena.

JAPANESE EARTH OBSERVING SYSTEM (JEOS)

The JEOS is being planned. It begins with the Advanced Earth Observing System (ADEOS) and the Tropical Rainfall Monitoring Mission (TRMM). A Japanese Polar-Orbiting Platform (JPOP) is expected to be launched in 1998. It will conduct global, continuous environmental monitoring from a sun-synchronous orbit. A second platform is being planned for a 2000 launch to measure main climate elements, such as wind field, precipitation, and radiation, from a non-sun-synchronous orbit. This mission will be a follow-on to TRMM and will promote better understanding of the diurnal variation process. Additional JEOS platforms under study may include Earth observation technology on the Japanese Experiment Module (JEM) and a geostationary satellite.

Plans call for the design of JPOP to be based on ADEOS and to focus on monitoring global hydrologic circulation, energy fluxes, atmospheric chemical composition, and elements of the hydrologic/cryospheric system. The observatory will secure global data acquisition through the use of data relay satellites, perhaps with a direct downlink capability as well. It will have a 5-year life, an evolving payload capability and mission operability, and standardized data transmission. No on-orbit serviceability is planned. A strawman list of approximately 30 candidate payloads has been proposed for the platform, including ADALT', AMSR, E-LIDAR, GLI, IMB', (D)PR, SLIES, TERSE, and TOMUIS. Of primary importance are AMSR, GLI, and E-LIDAR. Phase A studies of the platform and candidate payloads will be completed in 1991. An AO will be issued when the program enters Phase B.

- **ADAL'** is a two-frequency radar altimeter that will measure geoid, ocean waves, and polar ice, and will contribute to oceanic circulation and sea ice/ice sheet extent research. It possesses C, Ku, and Ka band frequencies with 330 to 1,000 MHz bandwidths. It has a 1.5-m conical scanning antenna and a pulse width 100 µsec.

- **AMSR** is a multi-frequency microwave radiometer that will be used to observe atmospheric and oceanic water vapor profiles such as precipitation, water vapor distribution, cloud water, sea surface temperature, sea ice, and sea surface wind speed. It employs six frequencies in the 6 to 90 GHz range (1.4 to 180 GHz is an option), with vertical and horizontal polarization, to secure a temperature resolution of 0.2 to 1.0K (goal) at 1K (goal) radiometric accuracy. The instrument design employs a 2-m antenna aperture, and is based on MSR (MOS-1) heritage.

- **E-LIDAR** is an experimental active optical sensor for measurement of aerosol and cloud (as a Mie scattering LIDAR), vertical profiles of water vapor profiles (as a differential absorption lidar [DIAL]), and ice sheet and sea level with very high accuracy (as a laser altimeter). It has a 720-730 nm (two-wave) laser with a 100-500 mJ/pulse, a 5-20 Hz duty cycle, 10 percent accuracy, and a 1-m telescope.

- **GLI** is an imaging spectrometer that will be used for global monitoring of biological/physical processes and stratospheric ozone in the spectral range from the ultraviolet to the thermal infrared. It possesses more than 20 bands from the ultraviolet to the thermal infrared with a bandwidth of 10-20 nm, and a signal-to-noise ratio of less than 1,000. It has a swath width greater than 1,800 km and an instantaneous field-of-view of less than 1 km. Instrument design is based on VTIR (MOS-1) and OCTS (ADEOS) heritage.

- **IMB'** is a multi-band optical radiometer covering visible to near-infrared that will measure the ecological environment with high spatial resolution. It possesses nine bands from 460-1,200 nm with a 20 (visible) to 1,000 nm (thermal-infrared) bandwidth. It has coarse and fine imaging modes, and a 100- to 1,000-km swath width. Instrument design is based on MESSR (MOS-1) and AVNIR (ADEOS).

- **(D)PR** is an active microwave sensor that will be used for 3-D measurement of global rain rate and will contribute to the study of hydrological circulation. It possesses frequencies of 13.8 GHz and/or 35.6 GHz, horizontal resolution of 8 km, and a 400-km swath width. It has a 137 slot array antenna with a 0.66° beam width. This instrument is based on PR (TRMM).

- **SLIES** is a Fourier transform Michelson interferometric spectrometer that will measure infrared emission of stratospheric and tropospheric minor species from limb and nadir. It possesses a band from 5 to 15 µm with a 0.05 cm^{-1} resolution (2-km vertical). It has a NEP of less than 0.1 $pW/Hz^{.5}$. Instrument heritage is based on IMG (ADEOS).

- **TERSE** is a near-infrared, high spectral resolution spectrometer that will provide global monitoring of tropospheric species (i.e., CH_4, H_20, N_2O, and CO_2) profiles by using a tunable etalon. It possesses 11 bands from 2,541 to 7,942 cm^{-1}, with a bandwidth of 5 cm^{-1} and a signal-to-noise ratio of greater than 500. It has a swath width of 500 km with a mechanical scan and an instantaneous field-of-view of 7.7 mrad.

- **TOMUIS** is an imaging spectrometer that will be used for 3-D mapping of stratospheric ozone distribution by measuring ultraviolet backscatter using a 64 x 32 element detector with thermo-electric cooling. It has a band from 260 to 320 nm with 0.3 nm resolution, and a swath width of 1,500 km.

POLAR-ORBITING ENVIRONMENTAL SATELLITES (POES)

NOAA's primary objective is to provide, with very high reliability, daily global data for operational forecasts and warnings. NOAA has two POES, one with a morning and one with an afternoon orbit; each is replaced as it nears the end of its 24-month design life. Over 120 countries depend on the data from POES' direct broadcast. The current NOAA system will continue through the launch of NOAA-M (p.m.) in 1997.

When NOAA-L reaches end-of-life, ESA's POEM-1 will continue NOAA's morning satellite service and will incorporate some NOAA instruments. POEM-1's operational instrument package will include AMSU-MHS (AMSU-B), S&R, SEM (MEPED and TED only), and a post-NOAA-N imager, microwave sounder, infrared sounder, and data collection system. Refer to the POEM section above for applicable instrument descriptions.

When NOAA-M reaches end-of-life, it will be replaced by NOAA-N to continue the afternoon satellite service. With the advent of NOAA-N, POES becomes part of the Mission to Planet Earth. NOAA-N will be a replica of NOAA-K,L,M. The instrument payload will include AVHRR-3, HIRS-3, AMSU-A/B, SBUV, SEM (MEPED and TED only), SARSAT, and ARGOS. At the end of its life, NOAA-N will be followed by a new NOAA-O,P,Q satellite series. Like POEM-1, these post-NOAA-N satellites will include MTS/MHS, S&R, SEM (MEPED, TED, and LEFI), and a post-NOAA-N imager, microwave sounder, infrared sounder, and data collection system. The instrument package will also include a post-NOAA-N solar backscatter ultraviolet monitor and total ozone monitor.

NOAA operational instruments—along with the research instruments provided by NASA, ESA, and Japan—are being designed with common instrument/platform interfaces to the greatest extent possible to facilitate future use of instruments on different platforms. For instance, NOAA might choose to fly NASA instruments currently designated as "pre-operational" on a continuation of the NOAA-O series afternoon spacecraft.

Direct broadcast of POEM and POES data will continue as with NOAA's current system. Data from potential operational instruments on the EOS-A and -B platforms will also be accessed and disseminated by NOAA.

POEM and POES (NOAA-N and following) satellite orbits will be maintained; no blind orbits will exist. In addition to direct-broadcast streams, all data will be broadcast to Fairbanks, Alaska, and Kiruna, Sweden. Full-resolution, Local Area Coverage (LAC) data will always be provided. There will be no need for low-resolution, Global Area Coverage (GAC) data. The automatic picture transmission (APT) and direct sounding broadcasts (DSB) of the current NOAA system will be replaced with low-resolution picture transmission (LRPT) broadcasts. The high-resolution picture transmission (HRPT) data rate will be changed from 667 kbps to 3.5 Mbps, and the HRPT frequency will be changed from its present value to 1704.5 MHz.

NOAA-N Instruments

- **AVHRR-3** will employ six spectral channels (five full time) at 0.58-0.68 μm, 0.72-1.00 μm, 1.58-1.64 μm (sun-side readout)/3.55-3.93 μm (dark-side readout), 10.3-11.3 μm, and 11.5-12.5 μm, with an image resolution of 1 to 4 km (effective 11-bit resolution). It will have an infrared calibration capability, but no visible calibration.

- **HIRS-3's** 20 channels will cover the ground to the troposphere, with 21-km nadir resolution (12-bit resolution), a scan line time of 6.4 secs, and full aperture calibration.

- **AMSU-A** will employ 15 channels to measure from ground level to 45 km, with 45-km nadir resolution (14-bit resolution). The scan line time of 8 secs includes full aperture calibration.

- **AMSU-B** will measure precipitation and water vapor profiles with two channels at 89.0 and 157.0 GHz, and three at 183.31 GHz (1, 3, and 7 GHz bandwidths). Its scan line time is 8 and 3 secs, respectively. The instrument has a 15-km nadir resolution (14-bit resolution) and full aperture calibration capability.

- **SBUV** will use 12 spectral channels that measure from 252.00-322.30 nm, with a 1.0 nm bandpass. The instrument has a 256-sec spectral scan, 11.33° x 11.33° instantaneous field-of-view, and 14-bit resolution. The diffuser plate calibration is accomplished with an onboard spectral reflectance/transmittance measurement system. SBUV operates only on the day side of the orbit, and performs spectral calibration on the night side.

- **SEM** is composed of MEPED and TED, as follows:

  – **MEPED** will measure charged particle flux from 30 KeV to more than 140 MeV. It measures pro tonin six spectral intervals, and electrons in three spectral intervals. MEPED possesses full in-flight calibration capability.
  – **TED** will measure charged particle flux from 0.05 to 20 KeV in two directions. It also possesses full in-flight calibration capability.

- **SARSAT** will receive beacon signals at 121.5, 243, and 406.05 MHz (-154 dBm signal detection level). The instrument transmits real-time at 1544.5 MHz to ground stations around the world. Over 1,400 lives have been saved to date through use of this instrument.

- **ARGOS** will receive platform and buoy transmissions on 401.65 MHz. At present, this data collection system monitors over 4,000 platforms worldwide. It outputs data via VHF link and stores them on tape.

Post-NOAA-N Instruments

- **Post-NOAA-N Imager** will employ seven full-time spectral channels: 0.605-0.625 µm, 0.860-0.880 µm, 1.580-1.640 µm, 3.620-3.830 µm, 8.400-8.700 µm, 10.30-11.30 µm, and 11.50-12.50 µm. The scan mode will be reversed from traditional imagers (i.e., now scans sun side to anti-sun side). Signal-to-noise ratio on all infrared channels will be 0.1° and 300K. It will image at 1-km resolution (12-bit resolution), and calibrate both the infrared and visible channels in-flight.

- **Post-NOAA-N Infrared Sounder** will employ 20 channels covering the ground to the troposphere, with 21-km nadir resolution (12-bit resolution) and full aperture calibration. The scan line time of 8 secs will include calibration.

- **MTS** will employ 21 channels covering ground level to 73 km, including upper atmosphere soundings. The instrument will provide full aperture calibration and 45-km nadir resolution (14-bit resolution). The scan line time of 8 secs will include calibration.

- **MHS** will measure precipitation and water vapor profiles with two channels at 89.0 and 150.0 GHz, and three at 183.31 GHz (1, 3, and 7 GHz bandwidths). Its scan line time will be 8 and 3 secs, respectively. It will possess full aperture calibration and 15-km nadir resolution (14-bit resolution). This instrument will be provided by EUMETSAT.

- **Total Ozone Monitor** will be a new addition to the -K,L,M series. Its six channels will measure ozone, SO2, and surface reflectivity at spectral intervals of 308.6, 313.0, 317.5, 331.2, 322.3, and 360.0 nm, with a 1-nm bandpass. The instrument will scan ±51.0° from nadir, with a full scan completed in 8 secs. It will have a 3.0° x 3.0° instantaneous field-of-view and 14-bit resolution. It will employ diffuser plate calibration with an onboard reflectance measurement system, and its signal-to-noise ratio will be greater than 30 at minimum scene radiance.

- **SBUV** will use 12 spectral channels that measure from 252.00-322.30 nm, with a 1.0 nm bandpass. The instrument will have a 256-sec spectral scan, 11.33° x 11.33° instantaneous field-of-view, and 14-bit resolution. The diffuser plate calibration will be accomplished with an onboard spectral reflectance/transmittance measurement system. SBUV will operate only on the day side of the orbit, and will perform spectral calibration on the night side.

- **SEM** will be composed of MEPED, TED, and LEFI, as follows:

  - **MEPED** will measure charged particle flux from 30 KeV to more than 140 MeV. It will measure protons in six spectral intervals, and electrons in three spectral intervals. MEPED will possess full in-flight calibration capability.
  - **TED** will measure charged particle flux from 0.05 to 20 KeV in two directions. It will also possess full in-flight calibration capability.
  - **LEFI** will measure the local electric field by sensing ion drift velocity. It will have a 2π steradian instantaneous field-of-view, 2- to 3-sec sampling rate, and ±500 mV/m range.

- **SARSAT** will receive beacon signals at 121.5, 243, and 406.05 MHz (-154 dBm signal detection level). The instrument will transmit real-time at 1544.5 MHz to ground stations around the world. This generation of SARSAT will have upgraded reliability and packaging over its predecessors.

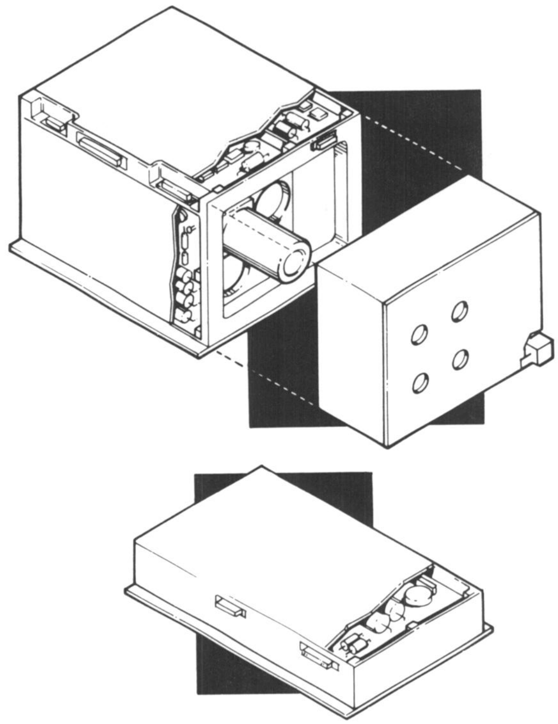
- **Post-NOAA-N Data Collection System** will be an upgraded ARGOS/3 instrument configuration. Its detectivity will be improved, enabling it to receive more simultaneous platform and buoy transmissions on 401.65 MHz. It will continue to monitor over 4,000 platforms worldwide, and output data via VHF link, also storing data on tape. This version will have upgraded reliability and packaging characteristics. ☆

EOS Instruments

ACRIM
AIRS, AMSU-A, & MHS
ALT
ASTER
CERES
EOS SAR
EOSP
GGI
GLRS
GOS
HIRDLS
HIRIS
IPEI
LAWS
LIS
MIMR
MISR
MLS
MODIS-N/T
MOPITT
SAFIRE
SAGE III
SOLSTICE II
STIKSCAT
SWIRLS
TES
XIE

ACRIM

Active Cavity Radiometer Irradiance Monitor



THREE TOTAL IRRADIANCE DETECTORS: ONE TO MONITOR SOLAR IRRADIANCE, TWO TO CALIBRATE OPTICAL DEGRADATION OF THE FIRST

HERITAGE: ACRIM II

MONITORS THE VARIABILITY OF TOTAL SOLAR IRRADIANCE

SOLAR IRRADIANCE UNCERTAINTY OF 0.1%; LONG-TERM PRECISION OF 5 PPM PER YEAR

SENSOR ASSEMBLY MOUNTED ON TWO-AXIS TRACKER TO OBSERVE SOLAR DISK DURING EACH ORBIT

The ACRIM experiment is designed to sustain the NASA long-term solar luminosity database. Its primary objective is to monitor the variability of total solar irradiance with state-of-the-art precision, extending the database compiled by other ACRIM experiments since 1980, as part of the Earth Radiation Budget thrust of the National Climate Program. An overlap strategy between succeeding ACRIM experiments provides the required long-term (multi-decadal) solar database precision, since the accuracy of the individual flight instruments is insufficient.

ACRIM data products will provide measurements of the total (bolometric) solar irradiance above the atmosphere, with absolute accuracy of 0.1 percent and long-term precision of 0.0005 percent per year. The measurements will be made continuously during satellite daylight passes, with integrated results at approximately 2-minute intervals. ☆

FOR FURTHER INFORMATION:

Willson, R.C. and H.S. Hudson, The Active Cavity Radiometer Irradiance Monitor, *Nature*, *332*, No. 6167, 810-812, 1988.

ACRIM Parameters

Measurement Approach

Three active cavity radiometers monitor total solar irradiance to 99.9% accuracy

Swath: n/a (looks at sun)
Spatial resolution: n/a

Accommodation Issues

Mass: 79 kg (including solar tracker)
Duty cycle: 100% (daylight only)
Power: 35 W (average), 50 W (peak)
Data rate: 1 kbps
Thermal control by: Heater, central thermal bus, radiator
Thermal operating range: 0-30°C
FOV: ±2.5°
Instrument IFOV: n/a
Pointing requirements (platform+instrument, 3σ):

Control:	1,800 arcsec
Knowledge:	1,800 arcsec
Stability:	15 arcsec
Jitter:	15 arcsec
Physical size:	60 x 60 x 60 cm

Principal Investigator—Richard C. Willson

Richard C. Willson holds a doctoral degree in Atmospheric Sciences from the University of California, Los Angeles, and B.S. and M.S. degrees in Physics from the University of Colorado. He is a member of the technical staff and Supervisor of the Solar Irradiance Monitoring Group, Atmospheric and Cometary Sciences Section, Earth and Space Sciences Division, at the Jet Propulsion Laboratory (JPL). His career, which began at JPL in 1963, has involved primarily the development of state-of-the-art Active Cavity Radiometer (ACR) pyrheliometry for use in solar total irradiance observations on balloon, sounding rocket, Space Shuttle, and satellite platforms. He has been the Principal Investigator for the Solar Maximum Mission ACRIM I, Space Shuttle Spacelab I, Atmospheric Laboratory for Applications and Science (ATLAS) I and ATLAS II/ACR, and Upper Atmosphere Research Satellite ACRIM II experiments.

Co-Investigator

Hugh S. Hudson, University of California, San Diego

AIRS, AMSU-A, and MHS

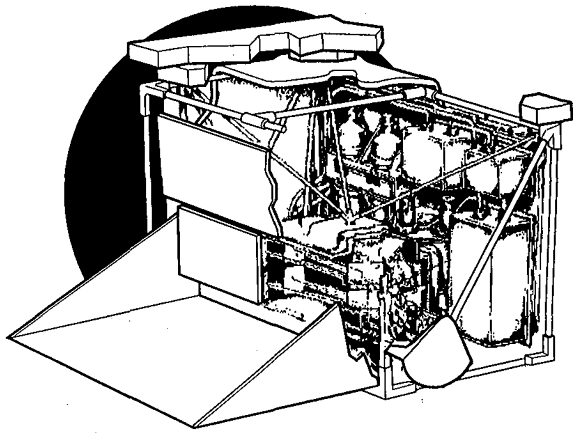
Atmospheric Infrared Sounder, Advanced Microwave Sounding Unit-A, and Microwave Humidity Sounder

AIRS

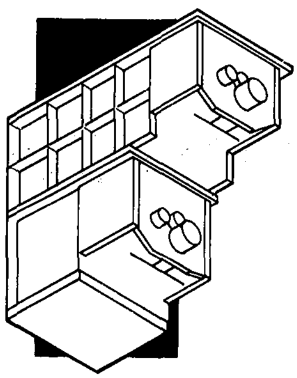
ATMOSPHERIC INFRARED SOUNDER

HERITAGE: HIRS 2, HIS

MEASURES THE EARTH'S OUTGOING RADIATION BETWEEN 0.4 TO 1.7 AND 3.4 TO 15.4 μM



Atmospheric Infrared Sounder



Advanced Microwave Sounding Unit-A

AMSU-A

MICROWAVE RADIOMETER

HERITAGE: MSU

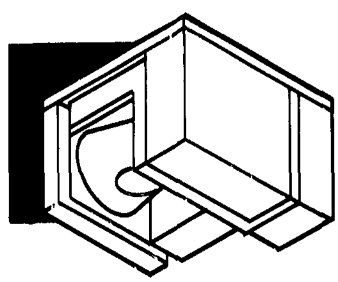
PROVIDES ATMOSPHERIC TEMPERATURE MEASUREMENTS FROM THE SURFACE UP TO 40 KM

MHS

MICROWAVE RADIOMETER

HERITAGE: MSU

PROVIDES ATMOSPHERIC WATER VAPOR PROFILE MEASUREMENTS



Microwave Humidity Sensor

AIRS is a facility instrument selected by NASA to fly on the EOS-A series. The same platform will also carry two operational microwave sounders: NOAA AMSU-A and the EUMETSAT MHS. AIRS is designed to meet NOAA's requirements for a high-resolution infrared (IR) sounder to fly on future operational weather satellites. AIRS, AMSU-A, and MHS measurements will be analyzed jointly to filter out the effects of clouds from the IR data in order to derive clear-column temperature profiles and surface temperatures with high vertical resolution and accuracy. Together, these instruments constitute the advanced operational sounding system, relative to the High-Resolution Infrared Sounder/Microwave Sounding Unit (HIRS/MSU) system that currently operates on NOAA satellites.

AIRS/AMSU-A/MHS will provide a wide range of data products. For the atmosphere, AIRS/AMSU-A/MHS will provide temperature profile, humidity profile, total precipitable water, fractional cloud cover, cloud-top height, and cloud-top temperature data. For the land, AIRS/AMSU-A/MHS will provide skin surface temperature, plus day and night land surface temperature difference. For the ocean, AIRS/AMSU-A/MHS will provide skin surface temperature. These instruments will also provide global measurements of outgoing day/night longwave surface flux.

AIRS

AIRS is a high spectral resolution sounder covering the spectral range between 0.4 and 15.4 µm, measuring simultaneously in over 3,600 spectral channels. The spectral resolution is 1,200 ($\lambda/\Delta\lambda$). The high spectral resolution enables separation of the contribution of unwanted spectral emissions and, in particular, provides spectrally clean "super windows," which are ideal for surface observations. All channels will be downlinked routinely.

Temperature profiles will be derived in the presence of multiple cloud layers without requiring any field-of-view to be completely clear. Humidity profiles will be derived from channels in the 6.3-µm water vapor band and the 11-µm windows, which are sensitive to the water vapor continuum. Determination of the surface temperature and surface spectral emissivity is essential for obtaining low-level water vapor distribution.

Land skin surface temperature and the corresponding IR emissivity are determined simultaneously with the retrieval of the atmospheric temperature and water profiles. Shortwave window channels near 3.4 µm are used to derive the surface temperature and corresponding spectral emissivity, and to account for reflected solar radiation. Once the surface temperature is determined, the longwave surface emissivity for the 11-µm region can be determined, then used to retrieve the water distribution near the surface.

Cloud-top heights and effective cloud amount are determined based on the calculated atmospheric temperature, humidity, and surface temperature, combined with the calculated clear-column radiance and measured radiance. The spectral dependence of the opacity of the clouds will distinguish various cloud types (including cirrus clouds).

Ozone retrieval is accomplished with the 9.6-µm ozone absorption band.

AIRS visible and near-IR channels between 0.4 and 1.7 µm will be used primarily to discriminate between low-level clouds and different terrain and surface covers, including snow and ice. In addition, the visible channels will allow the determination of cloud, land, and ocean surface parameters simultaneous with atmospheric corrections. Current implementation calls for six channels. One broadband channel from 0.4 to 1.0 µm will be used for the estimation of reflected shortwave radiation (i.e., albedo). Other channels will be used for surface properties such as ice and snow amount and cloud characterization.

AMSU-A and MHS

AMSU-A and MHS (formerly known as AMSU-B) have a total of 20 channels: 15 are assigned to AMSU-A, each having a 3.3° instantaneous field-of-view (IFOV), and five are assigned to MHS, each having a 1.1° IFOV. Channels 3 to 14 on AMSU-A are situated on the low-frequency side of the oxygen resonance band (50 to 60 GHz) and are used for temperature sounding. Successive channels in this band are situated at frequencies with increasing opacity, therefore responding to radiation from increasing altitudes. Channel 1, located on the first (weak) water vapor resonance line, is used to obtain estimates of total column water vapor in the atmosphere. Channel 2, at 31 GHz, is used to indicate the presence of rain.

Channel 15 on AMSU-A and channel 16 on MHS are both at 89 GHz, and are also used to indicate precipitation (i.e., at 89 GHz ice more strongly scatters radiation than it absorbs or emits). Channels 17 to 20 are located on the wings of the strongly opaque water vapor resonance line at 183.3 GHz. Again, successive channels in this group have decreasing opacity; therefore, they correspond to humidities at decreasing altitudes. Channels 17 to 20, along with inputs from channel 16 and channels 1 and 2, together with the temperature profile from AIRS/AMSU-A/MHS, are used to obtain profiles of atmospheric humidity (i.e., water vapor). ☆

FOR FURTHER INFORMATION:

AIRS Science Team, The Atmospheric Infrared Sounder (AIRS) science and measurement requirements, JPL Document #D6665.

AIRS Parameters

Measurement Approach

High spectral resolution, multispectral IR sounder
Operates with AMSU for all-weather capability
1K temperature retrieval accuracy
0.05 emissivity accuracy
Array grating spectrometer (3.4 to 15.4 µm), spectral resolution of 1,200 ($\lambda/\Delta\lambda$)
Six visible channels (0.4 to 1.7 µm)

Swath: 1,650 km
Spatial resolution: 13.5 km horizontal at nadir, 1 km vertical

Accommodation Issues

Mass: 114 kg
Duty cycle: 100%
Power: 295 W
Data rate: 2.0 Mbps
Thermal control by: Redundant 60K Stirling cycle coolers, heater, central thermal bus, two-stage radiator
Thermal operating range: 20-25°C
FOV: ±49.5° cross-track
Instrument IFOV: 1.1° circular
Pointing requirements (platform+instrument, 3σ):

Control:	TBD
Knowledge:	180 arcsec
Stability:	1.5 arcmin per TBD sec
Jitter:	TBD
Physical size:	80 x 95.3 x 116.5 cm (stowed) 158.7 x 95.3 x 116.5 cm (deployed)

AMSU-A Parameters

Measurement Approach

Passive microwave radiometer
Measures atmospheric temperature

Swath: 1,650 km
Spatial resolution: 40 km horizontal at nadir

Accommodation Issues

Mass: 100 kg
Duty cycle: 100%
Power: 122 W
Data rate: 3.2 kbps
Thermal control by: Heater, central thermal bus, radiator
Thermal operating range: 0-30°C
FOV: ±49.5°
Instrument IFOV: 3.3°
Pointing requirements (platform+instrument, 3σ):

Control:	0.2°
Knowledge:	0.1°
Stability:	0.1°
Jitter:	0.1°
Physical size:	TBD

MHS Parameters

Measurement Approach

Passive microwave radiometer for humidity profiling

Consists of five channels: 1 at 89.0 GHz, 1 at 166.0 GHz, and 3 at 183.3 GHz

Swath: 1,650 km

Spatial resolution: 13.5 km horizontal at nadir

Accommodation Issues

Mass: 60 kg

Duty cycle: 100%

Power: 90 W

Data rate: 4.2 kbps

Thermal control by: Radiator

Thermal operating range: TBD

FOV: ±49.5° cross-track from nadir (+90 to -49.5° for calibration)

Instrument IFOV: 1.1°

Pointing requirements (platform+instrument, 3σ):

Control: TBD

Knowledge: TBD

Stability: TBD

Jitter: TBD

Physical size: Approximately 66 x 65 x 47 cm

Team Leader—Moustafa Chahine

Moustafa Chahine was awarded a Ph.D. in Fluid Physics from the University of California at Berkeley in 1960. He is Chief Scientist at the Jet Propulsion Laboratory (JPL), where he has been affiliated for nearly 30 years. From 1978 to 1984, he was Manager of the Division of Earth and Space Sciences at JPL; as such, he was responsible for establishing the Division and managing the diverse activities of its 400 researchers.

For 20 years, Dr. Chahine has been directly involved in remote sensing theory and experiments. His resume reflects roles as Principal Investigator, designer and developer, and analyst in remote sensing experiments. He developed the Physical Relaxation Method for retrieving atmospheric profiles from radiance observations. Subsequently, he formulated a multispectral approach using infrared and microwave data for remote sensing in the presence of clouds. These data analysis techniques were successfully applied in 1980 to produce the first global distribution of the Earth surface temperature using the HIRS/MSU sounders data. Dr. Chahine was integrally involved in the design study of AMTS, the precursor to the current AIRS spectrometer. Dr. Chahine served as a member of the NASA Earth System Sciences Committee (ESSC), which developed the program leading to EOS, and currently is Chairman of the Science Steering Group of a closely related effort, the World Meteorological Organization's Global Energy and Water Cycle Experiment (GEWEX).

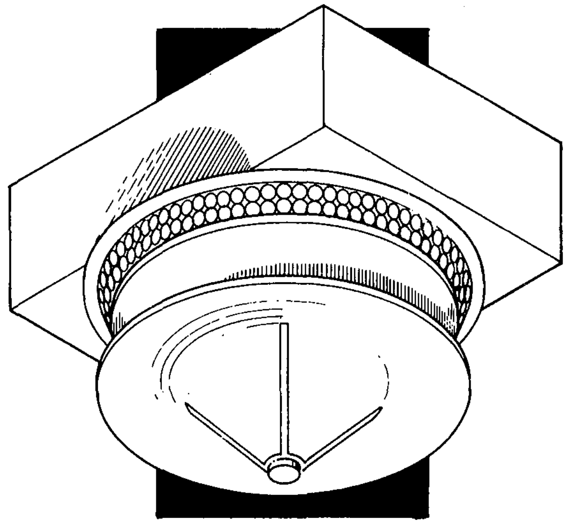
Dr. Chahine is a Fellow of the American Physical Society and the British Meteorological Society. In 1969, he was awarded the NASA Medal for Exceptional Scientific Achievements and, in 1984, the NASA Outstanding Leadership Medal.

Team Members

Hartmut H. Aumann, Jet Propulsion Laboratory
Alan I. Chedin, CNRS/CNES
Henry E. Fleming, NOAA/NESDIS
Catherine Gautier, University of California, Santa Barbara
John Francis LeMarshall, Bureau of Meteorology Research Centre
Larry M. McMillin, NOAA/NESDIS
Ralph Alvin Petersen, NOAA/NWS/NMC
Henry E. Revercomb, University of Wisconsin
Rolando Rizzi, Universita di Bologna
Philip Rosenkranz, Massachusetts Institute of Technology
William L. Smith, University of Wisconsin
David H. Staelin, Massachusetts Institute of Technology
L. Larrabee Strow, University of Maryland
Joel Susskind, Goddard Space Flight Center

ALT

ALTIMETER



DUAL FREQUENCY RADAR ALTIMETER

HERITAGE: TOPEX/POSEIDON

MAPS THE TOPOGRAPHY OF SEA SURFACE AND POLAR ICE SHEETS

MEASURES OCEAN WAVE HEIGHT AND WIND SPEED

PROVIDES INFORMATION ON THE OCEAN SURFACE CURRENT VELOCITY

ALT is a nadir-looking radar altimeter that maps the topography of the sea surface and polar ice sheets. The shape and strength of the radar return pulse also provide measurements of ocean wave height and wind speed, respectively. Through the mapping of sea surface topography, ALT provides information on the ocean surface current velocity, which, when combined with ocean models, can lead to a 4-D description of ocean circulation. The heat and biogeochemical fluxes carried by ocean currents hold the key to understanding the ocean's role in global changes in climate and biogeochemical cycles. Secondary research contributions of ALT data include the study of the variations in sea level and ice sheet volume in response to global warming/cooling and hydrological balance; the study of marine geophysical processes (such as crustal deformation) from the sea surface topography; and the monitoring of global sea state from the wave height and wind speed measurement.

ALT uses radar pulse timing to determine the vertical distance from the spacecraft to the sea surface. Knowledge of the spacecraft altitude and corrections for pulse delays due to the ionosphere and to tropospheric water vapor are required to accurately retrieve sea surface height. Use of two independent altimeters, one at Ku band (13.8 GHz) and the other at S band (3.2 GHz), allows for determination of the pulse propagation delay due to the ionosphere. The average received pulse power as a function of the slope of the leading edge of the returned pulse is used to determine significant wave height, and the net signal strength (determined by the scattering cross section of the ocean surface) can then be related empirically to the surface scalar wind speed.

ALT will provide ocean ice-sheet topography maps with 50-cm height accuracy and 15-km resolution; along-track sea surface height with 10-cm height accuracy and 7-km resolution; sea-surface topography maps with 5-cm height accuracy and 25-km resolution; and ocean tide models with 2-cm height accuracy and 1° resolution. Other products include along-track wind speeds with 2 m/sec accuracy and 7-km resolution, and along-track wave heights with an accuracy of 0.5 m or 10 percent of the actual value, whichever is greater (also with 7-km resolution). ✰

FOR FURTHER INFORMATION:

Fu, L-L., D.B. Chelton, and V. Zlotnicki, Satellite altimetry: Observing ocean variability from space, *Oceanography Magazine*, *1*, 2, 4-11, 1988.

ALT Parameters

Measurement Approach
Active microwave time-of-flight altitude measurement
Dual frequency: 13.6 GHz (Ku) and 5.3 GHz (C) for ionospheric correction
Nadir viewing

Swath: TBD
Spatial resolution: TBD

Accommodation Issues
Mass: 275 kg
Duty cycle: 100%
Power: 232 W (average), 250 W (peak, calibration only)
Data rate: 80 kbps
Thermal control by: Heater, central thermal bus, radiator
Thermal operating range: 0-35°C
FOV: TBD° beam cone centered about nadir
Instrument IFOV: n/a
Pointing requirements (platform+instrument, 3σ):

Control:	TBD
Knowledge:	TBD
Stability:	TBD
Jitter:	TBD
Physical size:	TBD

Requires passive microwave radiometer for water vapor correction and precise positioning system for orbit height correction.
Requires observatory orbit-adjust maneuvers to maintain repeat ground track.

Team Leader—Lee-Lueng Fu

Lee-Lueng Fu received a B.S. in Physics from the National Taiwan University in 1972, and a Ph.D. in Oceanography from the Massachusetts Institute of Technology and Woods Hole Oceanographic Institution in 1980. He has been with the Jet Propulsion Laboratory (JPL) since 1980, and is currently Supervisor of the Physical Oceanography Group, Atmospheric and Oceanography Sciences Section. Dr. Fu's research interests involve analyzing satellite remote sensing observations for the study of ocean currents and waves. His recent activities have been focused on the use of satellite altimetric measurement for the study of large-scale ocean circulation and its variability. In recognition of this effort, he was the recipient of the JPL Director's Research Achievement Award in 1986. Dr. Fu is a Principal Investigator on the science teams of the NASA Scatterometer (NSCAT) Project and the TOPEX/Poseidon mission (an altimetric mission in collaboration with France to study ocean circulation). For the latter, he also serves as Project Scientist at JPL. Dr. Fu has served on numerous NASA Earth science committees, including the EOS Science Steering Committee.

Team Members

Francois Barlier, Groupe de Recherches de Geodesie Spatiale, France
George Born, University of Colorado
Claude Boucher, Institut Geographique National, France
Derek Burrage, Australian Institute of Marine Science, Australia
Anny Cazenave, Groupe de Recherches de Geodesie Spatiale, France
Dudley Chelton, Oregon State University
John Church, Commonwealth Scientific and Industrial Research Organization, Australia
Pierre de Mey, Groupe de Recherches de Geodesie Spatiale, France
Yves Desaubies, Institut Francais de Recherche Pour l'Exploration de la Mer, France
Bruce Douglas, NOAA/National Ocean Service
Marten Grundlingh, National Research Institute for Oceanology, South Africa
Eli Katz, Columbia University
Michel Lefebvre, Groupe de Recherches de Geodesie Spatiale, France
Christian Le Provost, Institut de Mechanique de Grenoble, France
Timothy Liu, Jet Propulsion Laboratory
Roger Lukas, University of Hawaii
James Marsh, Goddard Space Flight Center
Yves Menard, Groupe de Recherches de Geodesie Spatiale, France
Jacques Merle, Universite de Paris, France
Jean-Francois Minster, Groupe de Recherches de Geodesie Spatiale, France
James Mitchell, Naval Ocean Research and Development Activity
Dirk Olbers, Alfred Wegener Institut fur Polar und Meeresforschung, FRG
Michael Ollitrault, Institut Francais de Recherche Pour l'Exploration de la Mer, France
Lasse Pettersson, University of Bergen, Norway
Joel Picaut, Centre ORSTROM de Noumea, New Caledonia
Richard Rapp, Ohio State University
Braulio Sanchez, Goddard Space Flight Center
Jiro Segawa, Ocean Research Institute, Japan
Anne Souriau, Groupe de Recherches de Geodesie Spatiale, France
Ted Strub, Oregon State University
Chang-Kou Tai, Scripps Institution of Oceanography
Keisuke Taira, Ocean Research Institute, Japan
Byron Tapley, University of Texas, Austin
Pascal Tarits, Institut de Physique du Globe de Paris, France
John Wahr, University of Colorado
Karrel Wakker, Delft University of Technology, The Netherlands
Phillip Woodworth, Proudman Oceanographic Laboratory, United Kingdom
Carl Wunsch, Massachusetts Institute of Technology

ASTER

ADVANCED SPACEBORNE THERMAL EMISSION AND REFLECTION RADIOMETER

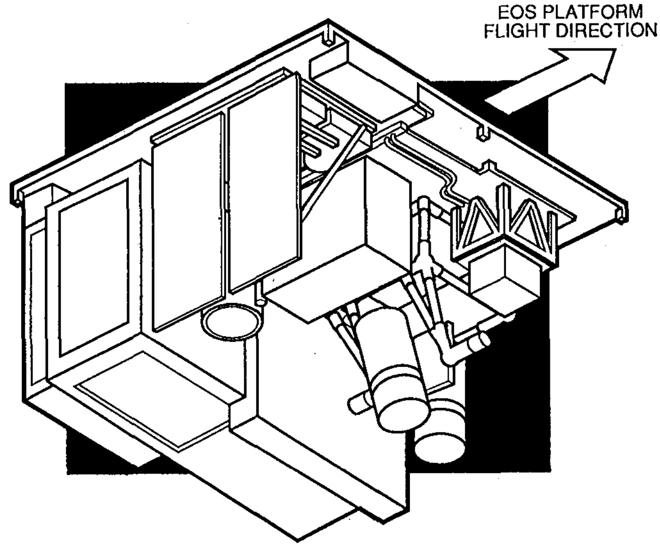
IMAGING RADIOMETER

HERITAGE: MESSR, OPS, LANDSAT, AND SPOT

PROVIDES HIGH SPATIAL RESOLUTION IMAGES OF THE LAND SURFACE, WATER, AND CLOUDS

SAME ORBIT STEREO CAPABLE

14 MULTISPECTRAL BANDS FROM VISIBLE THROUGH THERMAL INFRARED



ASTER, formerly known as the Intermediate Thermal Infrared Radiometer (ITIR), is a facility instrument provided for the EOS-A platform series under an agreement with Japan. ASTER will operate in three visible and near-infrared (VNIR) channels between 0.5 and 0.9 µm, with 15-m resolution; six shortwave infrared (SWIR) channels between 1.6 and 2.5 µm, with 30-m resolution; and five thermal infrared (TIR) channels between 8 and 12 µm, with 90-m resolution. The instrument will have 4 percent absolute radiometric accuracy in the VNIR and SWIR, and 2K absolute temperature accuracy (240 to 370K), over a 60-km swath whose center is pointable cross-track ±106 km. One of the VNIR channels will provide along-track stereo views with a base-to-height ratio of 0.6, which will be used for stereoscopic observation of local topography, cloud heights, volcanic plumes, and generation of local surface digital elevation models (DEMs). ASTER pointing capabilities will be such that any point on the globe shall be accessible at least once every 16 days.

ASTER's science objectives include surface and cloud imaging with high spatial resolution and with multispectral channels from visible to thermal infrared. ASTER will be used synergistically with MODIS, MISR, and AIRS.

ASTER multispectral TIR data can be used to assist in separating brightness temperature into spectral emissivity and kinetic temperature. Setting emissivity in one band to a constant, using *a priori* knowledge where feasible, permits solving for temperature in that band, then for the emissivities of the other four bands. An interactive procedure is then used to get best estimates of both temperature and emissivities, using cover type based on atlas information or other ASTER bands.

Surface kinetic temperature can be used to determine elements of surface process models, leading to analyses of radiative heat flux, sensible heat flux, latent heat flux, and ground heat conduction. Surface temperatures are also related to thermophysical properties (such as thermal inertia), vegetation health, evapotranspiration, and temporal land classification (e.g., wet vs. dry, vegetated vs. bare soil, etc.).

ASTER data products will exploit combinations of VNIR, SWIR, and TIR for soil and rock studies, for volcano monitoring, and for surface temperature, emissivity, and reflectivity determination. VNIR and SWIR bands will be used for investigation of land use patterns and vegetation, VNIR and TIR combinations for the study of coral reefs and glaciers, and VNIR for DEMs. TIR channels will be used for study of evapotranspiration, and land and ocean temperature. ☆

FOR FURTHER INFORMATION:

Fujisada, H. and M. Ono, Overview of ASTER design concept, Society of Photo-Optical Instrumentation Engineers, vol. 1490, April 1991.

ASTER Parameters

Measurement Approach

Multispectral imager for reflected and emitted radiation
Measurements of Earth's surface
4% absolute radiometric accuracy in VNIR and SWIR bands
Absolute temperature accuracy is 3K in 200 to 240K range, 2K in 240 to 270K range, 1K in 270 to 340K range, and 2K in 340 to 370K range for TIR bands

Swath: 60 km at nadir; swath center is pointable cross-track ±106 km
Spatial resolution:
- VNIR (0.5-0.9 μm), 15 m
  - Stereo (0.7-0.9 μm), 15 m horizontal, 25 m vertical
- SWIR (1.6-2.5 μm), 30 m
- TIR (8-12 μm), 90 m

Accommodation Issues

Mass: 352 kg
Duty cycle: 8% (VNIR and SWIR, daylight only); 16% (TIR)
Power: 377 W (average), 650 W (peak)
Data rate: 8.3 Mbps (average), 89.2 Mbps (peak)
Thermal control by: 80K Stirling cycle coolers, heaters, central thermal bus, radiators
Thermal operating range: 10-28°C
FOV (all pointing is near-nadir except VNIR forward, which is 29.7° forward of nadir):
- TIR = SWIR = 4.9° (nadir) x IFOV
- VNIR = 6.09° (nadir) x IFOV, 5.19° (forward) x IFOV

Instrument IFOV:
- SWIR = 43 μrad (nadir)
- TIR = 128 μrad (nadir)
- VNIR = 21 μrad (nadir), 18.1 μrad (forward)

Pointing requirements (platform+instrument, 3σ):

Control:	1 km on ground (all axes)
Knowledge:	400 m on ground (all axes)
Stability:	2 pixels per 60 sec (roll = 8.8, pitch = 8.8, yaw = 15 arsec)
Jitter:	1-2 pixels per 9 sec (roll = 8.8, pitch = 4.4, yaw = 52 arcsec)
Physical size:	1.6 x 1.6 x 0.9 m envelope

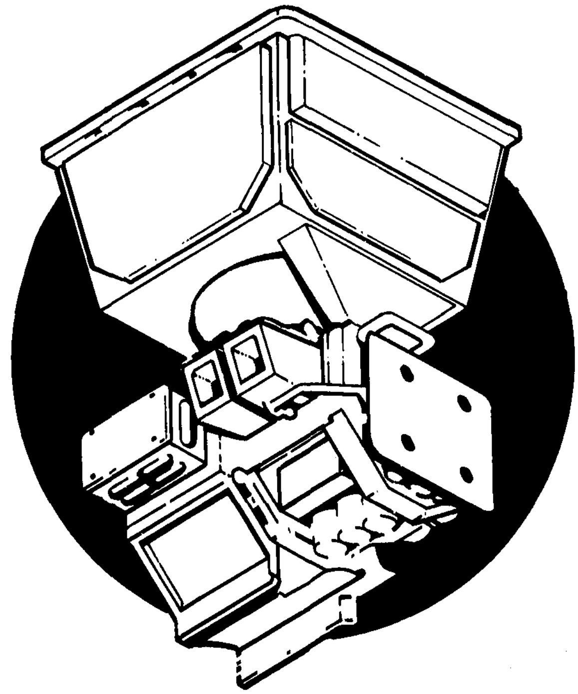
Team Members

Hiroji Tsu, Geological Survey of Japan (Team Leader)
Anne B. Kahle, Jet Propulsion Laboratory (U.S. Team Leader)

Francois Becker, Universite Louis Pasteur de Strasbourg
Philip R. Christensen, Arizona State University
Hiroyuki Fujisada, Electro Technical Laboratory
Alan R. Gillespie, University of Washington
Yoshinori Ishii, The University of Tokyo
Hugh H. Kieffer, U.S. Geological Survey
Motoaki Kishino, The Institute of Physical and Chemical Research
Shigeyuki Ohbayashi, Science University of Tokyo
Akira Ono, National Research Laboratory of Metrology
Frank Palluconi, Jet Propulsion Laboratory
David Pieri, Jet Propulsion Laboratory
Laurence C. Rowan, U.S. Geological Survey
Shuichi Rokugawa, The University of Tokyo
John W. Salisbury, The Johns Hopkins University
Isao Sato, Geological Survey of Japan
Thomas Schmugge, USDA/Hydrology Laboratory
Naotatsu Shikazono, Keio University
Phillip N. Slater, University of Arizona
Tsutomu Takashima, Meteorological Research Institute
Hiroshi Watanabe, JAPEX Geoscience Institute, Inc.
Ronald Welch, South Dakota School of Mines & Technology
Yasushi Yamaguchi, Geological Survey of Japan
Yoshifumi Yasuoka, National Institute for Environmental Studies

CERES

Clouds and Earth's Radiant Energy System



TWO BROADBAND, SCANNING RADIOMETERS: ONE CROSS-TRACK MODE, ONE ROTATING PLANE

HERITAGE: ERBE

MEASURES EARTH'S RADIATION BUDGET AND ATMOSPHERIC RADIATION FROM THE TOP OF THE ATMOSPHERE TO THE SURFACE

THREE CHANNELS IN EACH RADIOMETER: TOTAL RADIANCE (0.2 TO >100 μM), SHORTWAVE (0.2 TO 3.5 μM), AND LONGWAVE (6 TO 25 μM)

ALSO A CANDIDATE FOR FLIGHT ON TRMM AND POEM-1

The instruments of the CERES investigation will provide EOS with an accurate and self-consistent cloud and radiation database. Cloud and radiation flux measurements are fundamental inputs to models of oceanic and atmospheric energetics, and will also contribute to extended range weather forecasting. These data have been requested for international programs of the World Climate Research Program (WCRP), including TOGA, WOCE, and GEWEX.

Clouds are one of the largest sources of uncertainty in humankind's understanding of climate. CERES will permit retrieval of cloud parameters in terms of measured areal coverage, altitude, liquid water content, and shortwave and longwave optical depths. CERES will use a longwave and shortwave threshold technique for 21-km resolution cloud retrievals. A retrieval with 4.5-μm band CO_2 radiances from other instrument measurements will improve detection of cirrus. Also, spatial coherence, hybrid bispectral threshold, and texture analysis will be used for further improving cloud property retrievals.

Surface radiation budget and atmospheric shortwave flux divergence will be computed using the relationship between the shortwave top of the atmosphere fluxes from CERES and the shortwave flux at the Earth's surface. Radiative transfer calculations and satellite measurements of atmospheric properties will be used to determine atmospheric flux divergence profiles; satellite-measured surface temperature and estimates of albedo and emissivity will be used to obtain longwave and shortwave components of the radiative fluxes at the Earth's surface.

Radiation will be provided as fluxes at the top of the Earth's atmosphere, at the Earth's surface, and as flux divergences within the atmosphere. Thus, these instruments will continue the long-term measurement of the Earth's radiation budget, and provide continuity with the Earth Radiation Budget Experiment (ERBE) and pre-ERBE measurements. Measurement of clear-sky fluxes will aid in the understanding of hypothesized climate forcing and feedback mechanisms involving surface radiative characteristics.

Time interpolation and averaging will be used to obtain synoptic values from instantaneous measurements through optimal data sampling from multiple platforms. Geostationary satellite data will be used to fill in missing times and regions. Improved methods of time-space assimilation and interpolation across data voids will also be used. ☆

FOR FURTHER INFORMATION:

Barkstrom, B.R., Long-term monitoring of the Earth's radiation budget, in *Proceedings of the Society of Photo-Optical Instrumentation Engineers*, vol. 1299, Bellingham, WA, 1990.

CERES Parameters

Measurement Approach

Measures longwave and shortwave infrared radiation using thermistor bolometers to determine the Earth's radiation budget

First instrument (cross-track scanning) will essentially continue the ERBE mission

Second instrument (azimuthally scanning) will provide angular flux information that will improve accuracy of current models

Swath: Limb to limb

Spatial resolution: 21 km at nadir

Accommodation Issues

Mass: 80 kg

Duty cycle: 100%

Power: 70 W (average), 90 W (peak)

Data rate: 20 kbps

Thermal control by: Heaters, radiators

Thermal operating range: 1.3-13.4°C (electronics) and 20-38°C (detectors)

FOV: ±78° cross-track, 360° azimuth

Instrument IFOV: 14 mrad

Pointing requirements (platform+instrument, 3σ):

Control:	3,600 arcsec
Knowledge:	180 arcsec
Stability:	TBD
Jitter:	TBD

Physical size: 0.403 x 0.403 x 0.549 m per unit (stowed)
0.403 x 0.403 x 0.632 m per unit (deployed)

Principal Investigator—Bruce Barkstrom

Bruce Barkstrom received a B.S. in Physics from the University of Illinois. He received an M.S. and Ph.D. in Astronomy from Northwestern University. Following a position as Research Associate with the National Center for Atmospheric Research, he had a 5-year teaching assignment with George Washington University. In 1979, Dr. Barkstrom joined NASA/Langley Research Center. He serves as the ERBE Experiment Scientist and Science Team Leader. As such, he is directly responsible for the ERBE instrument design and calibration, as well as the ERBE data interpretation. He is also responsible for science project management of a team of 17 Principal and 40 Co-Investigators.

Co-Investigators

Maurice L. Blackman, NOAA/Environmental Research Laboratory
Robert D. Cess, State University of New York
Thomas P. Charlock, Langley Research Center
James A. Coakley, Oregon State University
Dominique Crommelynck, Royal Meteorological Institute, Belgium
Wayne L. Darnell, Langley Research Center
Richard N. Green, Langley Research Center
Edwin F. Harrison, Langley Research Center
Robert S. Kandel, Ecole Polytechnique
Michael D. King, Goddard Space Flight Center
Robert B. Lee III, Langley Research Center
Alvin J. Miller, NOAA/National Meteorological Center
Patrick Minnis, Langley Research Center
V. Ramanathan, Scripps Institution of Oceanography
David A. Randall, Colorado State University
G. Louis Smith, Langley Research Center
Larry L. Stowe, NOAA/NESDIS
John T. Suttles, Langley Research Center
Ronald Welch, South Dakota School of Mines & Technology
Bruce A. Wielicki, Langley Research Center

EOS SAR

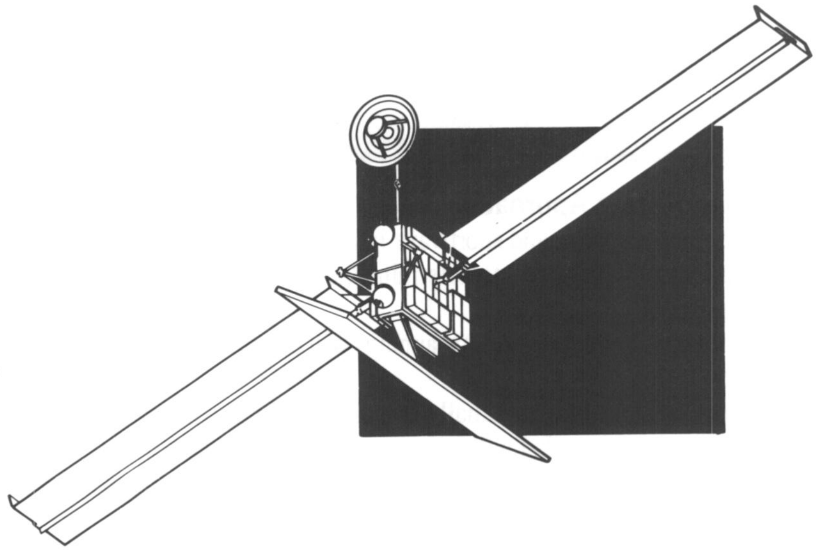
EOS Synthetic Aperture Radar

THREE-FREQUENCY (L, C, AND X BAND), MULTIPOLARIZATION IMAGING RADAR

HERITAGE: SEASAT SAR, SIR-A, SIR-B, SIR-C/X-SAR

MONITORS GLOBAL DEFORESTATION AND ITS IMPACT ON GLOBAL WARMING; SOIL, SNOW, AND CANOPY MOISTURE AND FLOOD INUNDATION, AND THEIR RELATIONSHIP TO THE GLOBAL HYDROLOGIC CYCLE; AND SEA ICE PROPERTIES AND THEIR IMPACT ON POLAR HEAT FLUX

DEDICATED DELTA LAUNCH



EOS SAR provides global coverage and frequent repeat access for monitoring dynamic phenomena; the capability to acquire all-weather and day/night inventory information in all seasons, at all latitudes, and in intensively cloudy areas (e.g., the tropics and polar regions); and the ability to collect high spatial resolution data for various process studies. EOS SAR will monitor soil, snow, and canopy moisture and flood inundation, and their relationship to the global hydrologic cycle; global deforestation and forest biomass, and their impact on the global carbon cycle; and sea ice properties and their impact on polar heat flux.

EOS SAR is a single instrument mission to be launched within 1 year of the EOS-A platform. The plan is for a new start in 1994-95, launch of a 5-year lifetime EOS SAR in 1999, followed by subsequent launches in 2004 and 2009, and the mission terminating in 2014.

The EOS SAR has capabilities for multifrequency multipolarization measurements in the L band (HH, VV, HV, VH, phase), plus C and X bands (HH, VV, phase). The instrument uses electronic beam steering in the cross-track direction to acquire images at selectable incidence angles from 15 to 50°. The EOS SAR has a varying spatial resolution and swath width capability in three modes as follows: 20- to 30-m resolution with a swath width of 30 to 50 km (the Local High Resolution mode), 50- to 100-m resolution with a 100- to 200-km swath (the Regional Mapping mode), and 250- to 500-m resolution with a swath width of up to 500 km (the Global Mapping mode).

The EOS SAR has a mass of 1,300 kg, a data rate of 180 Mbps peak and 15 Mbps average, and requires 1.6 kW average power. The EOS SAR is scheduled to fly on a dedicated platform, launched by a Delta II class vehicle into a 620-km altitude, sun-synchronous orbit with an afternoon equator crossing time. The EOS SAR X band is to be provided by the Federal Republic of Germany. ☆

FOR FURTHER INFORMATION:

Way, J. and E.A. Smith, The evolution of synthetic aperture radar systems and their progression to the EOS SAR, *IEEE Transactions on Geoscience and Remote Sensing*, 1991 (in press).

EOS SAR Parameters

Measurement Approach
Three frequency (L, C, and X band) multipolarization SAR that operates from a Local High Resolution to a Global Mapping mode capable of imaging 80% of the Earth's surface every 5 days

Geophysical products generated from the SAR image data include forest biomass and deforestation extent; soil, vegetation, and snow moisture; sea ice type and motion; and geomorphological properties

Mode
Local High Resolution: 30- to 50-km swath, 20- to 30-m spatial resolution

Regional Mapping: 100- to 200-km swath, 50- to 100-m spatial resolution

Global Mapping: 350- to 500-km swath, 250- to 500-m spatial resolution

Accommodation Issues
Mass: 1,100 kg

Duty cycle: ~30%

Power: 1.6 kW (average), 5.8 kW (peak)

Data rate: 15 Mbps (average), 180 Mbps (peak)

Thermal control: Not required

Thermal operating range: TBD

FOV: 15-50° look angle from nadir, both sides of nadir

Instrument IFOV: 30-500 km

Pointing requirements (platform+instrument, 3σ):

Control:	0.5°
Knowledge:	0.05°
Stability:	0.01°
Jitter:	TBD

Physical size: 1.5 x 1.5 x 1.5 m (electronics), 2.6 x 10.8 m (deployed antenna)

Team Leader—Charles Elachi

Charles Elachi received his undergraduate degree in Physics from the University of Grenoble in France in 1968, and went on to earn a Ph.D. in Electrical Sciences from the California Institute of Technology. He holds a second M.S. in Geology from the University of California, Los Angeles, and an M.B.A. from the University of Southern California. He has been affiliated with the Jet Propulsion Laboratory (JPL) and the California Institute of Technology (CIT) since 1971; in addition to lecturing at CIT, he is JPL's Assistant Laboratory Director for Space Science and Instruments.

Dr. Elachi has concentrated his research on the use of spaceborne active microwave instruments and remote sensing of planetary surfaces, atmospheres, and subsurfaces. He has served as Principal Investigator (PI) for over a dozen NASA research studies dating back to Apollo 17. He was PI on SIR-A, the first scientific payload carried on the Space Shuttle, and the follow-on SIR-B, and is the Team Leader on SIR-C/X-SAR; he has also been responsible for or participated in a number of mission/sensors development studies. He is the author of nearly 200 publications and two textbooks related to these interests, and holds four patents in the fields of interpretation of active microwave remote sensing data, wave propagation and scattering, electromagnetic theory, lasers, and integrated optics.

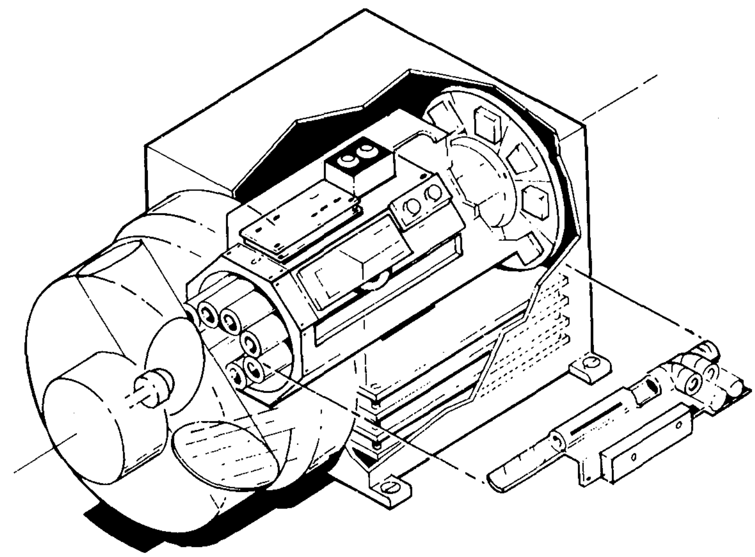
Among his other professional activities, he participates in numerous committees, commissions, working groups, and advisory boards; most relevant in this context was his role as Co-Chairman of the EOS SAR Science Panel from 1985 to 1987. Dr. Elachi is a member of the National Academy of Engineering and a Fellow of the IEEE. Among his numerous awards are the NASA Exceptional Scientific Achievement Medal and the William T. Pecora Award.

Team Members

Frank Carsey, Jet Propulsion Laboratory
Edwin Engman, Goddard Space Flight Center
Diane Evans, Jet Propulsion Laboratory
Johnny Johannessen, Nansen Remote Sensing Center
Eric Kasischke, Environmental Research Institute of Michigan
William J. Plant, Woods Hole Oceanographic Institution
K. Jon Ranson, Goddard Space Flight Center
Gerald G. Schaber, U.S. Geological Survey
Herman Shugart, University of Virginia
Fawwaz T. Ulaby, University of Michigan
JoBea Way, Jet Propulsion Laboratory
Howard A. Zebker, Jet Propulsion Laboratory

EOSP

Earth Observing Scanning Polarimeter



CROSS-TRACK SCANNING POLARIMETER

HERITAGE: PIONEER VENUS CPP, GALILEO PPR

GLOBALLY MAPS RADIANCE AND LINEAR POLARIZATION OF REFLECTED AND SCATTERED SUNLIGHT FOR 12 SPECTRAL BANDS FROM 410 TO 2,250 NM

PROVIDES GLOBAL AEROSOL DISTRIBUTION

PROVIDES CLOUD PROPERTIES SUCH AS OPTICAL THICKNESS AND PHASE

The EOSP will provide global maps of cloud and aerosol properties from retrievals of 12-channel radiance and polarization measurements in the visible and near-infrared. EOSP employs cross-track limb-to-limb scanning with contiguous 10-km nadir instantaneous field-of-view. The polarization and radiance measurements, combined with phase angle information, will be used to retrieve cloud and aerosol properties, including optical thickness, particle size, liquid/ice phase, and cloud-top pressure. EOSP measurements will also be used to retrieve global aerosol distribution and optical thickness in the troposphere and stratosphere. These data will provide atmospheric corrections for clear-sky ocean and land observations, and will also be applied to the study of vegetation and land surface characteristics.

The significant feature of EOSP as compared to other EOS instruments is its use of polarimetry in addition to intensity measurements; previous instrumentation relied solely on radiance intensity measurements. Polarization is significantly more sensitive to particle size and optical properties than is intensity. Analysis of the EOSP signals will proceed in two phases. In the first phase, a "cloud" algorithm will be used to divide the data into the two optical depth ranges that generally separate water clouds from other aerosols. This separation will make use of intensity and polarization information in all 12 EOSP spectral bands. A combination of intensity and polarization measurements will lead to determination of cloud optical thickness. For optically thin clouds, polarization is known to be a much more sensitive measure of optical thickness than is intensity. Cloud-top pressure determinations are based on measurements of Rayleigh scattering, which is proportional to the pressure. Water clouds give a distinct "rainbow" polarization signal, whereas ice clouds do not, thus providing the basis for particle-phase determination. For water clouds, the strength and precise location in phase angle of the rainbow feature determine cloud particle size.

Aerosol optical thickness will be calculated from measurements taken of cloud-free areas. The determination will be based on the characteristic behavior of polarization (i.e., optically thinner layers exhibit higher polarization degree). This is particularly true in the expected regions having optical thickness 0.01 to 1. The quantification of aerosol properties also provides atmospheric correction information, a significant by-product of importance to the surface imagers on the EOS platform.
The technique used here will be to compile a global aerosol

climatology, then parameterize the corrections for a limited number of typical situations.

EOSP products will fall into three major categories: Atmospheric cloud properties, aerosol properties, and atmospheric correction radiances to be furnished to the other surface imagers on the EOS platform. One global map per day will be furnished for each of the EOSP products. The use of polarimetry for characterization of vegetation and land is to be the subject of exploratory investigation. ☆

FOR FURTHER INFORMATION:

Brown, F.G. and E.E. Russell (Santa Barbara Research Center), Earth Observing Scanning Polarimeter, Phase B Final Report, Contract #NAS5-30756, DM LB870016, December 1990.

EOSP Parameters

Measurement Approach

Simultaneous measurement of radiance and linear polarization degree in 12 spectral bands from 410 to 2,250 nm
Spectral radiances accurate to 5%
Polarization accurate to 0.2%
Combined use of phase angle, multispectral radiance, and linear polarization degree information to determine cloud/aerosol properties

Swath: ±65° (limb-to-limb scan)
Spatial resolution: 10 km at nadir

Accommodation Issues

Mass: 19 kg
Duty cycle: 100%
Power: 14 W (normal), 22 W (peak)
Data rate: 44 kbps (orbit average), 88 kbps (peak, daylight only)
Thermal control by: Heaters, radiators; 185K radiator for SWIR detector cold focal plane
Thermal operating range: 0-40°C
FOV: ±65° cross-track
Instrument IFOV: 14.2 mrad
Pointing requirements (platform+instrument, 3σ):
Control: 3,600 arcsec
Knowledge: 150 arcsec
Stability: 100 arcsec per 10 arcsec
Jitter: 100 arcsec per 10 sec
Physical size: 0.51 x 0.26 x 0.81 m (stowed)
0.51 x 0.56 x 0.81 m (deployed)

Principal Investigator—Larry D. Travis

Larry D. Travis received a Ph.D. from Pennsylvania State University in 1971. He is currently the Associate Chief at the NASA Goddard Institute for Space Studies. His research interests include radiative transfer single and multiple scattering theory, theoretical interpretation of planetary polarization, and satellite platform measurements of planetary polarization. Dr. Travis serves as Principal Investigator for the Pioneer Venus Cloud Photopolarimeter Experiment and as a Co-Investigator for the Galileo Photopolarimeter Radiometer Experiment.

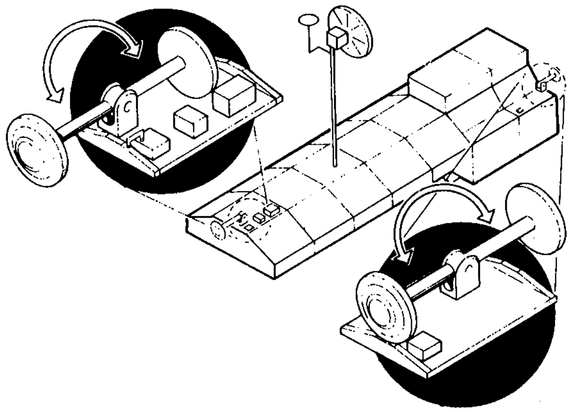
Co-Investigators

F. Gerald Brown, Santa Barbara Research Center
Andrew Lacis, Goddard Institute for Space Studies
William B. Rossow, Goddard Institute for Space Studies
Edgar E. Russell, Santa Barbara Research Center

GGI

GPS Geoscience

Instrument



GPS FLIGHT RECEIVER-PROCESSOR

HERITAGE: GPS RECEIVER ON TOPEX/POSEIDON

INCLUDES 18 DUAL-FREQUENCY SATELLITE CHANNELS, THREE ANTENNAE, AND A NETWORK OF 10 GPS GROUND RECEIVERS

ALLOWS REAL-TIME PLATFORM POSITION ACCURACY TO 1 M, AND POST-PROCESSING ACCURACY TO BETTER THAN 3 CM

CONTRIBUTES TO DEVELOPING CM-LEVEL GLOBAL GEODESY, HIGH-PRECISION ATMOSPHERIC TEMPERATURE PROFILING, IONOSPHERIC GRAVITY WAVE CHARACTERIZATION, AND 3-D IONOSPHERIC TOMOGRAPHY

GGI is a high-performance Global Positioning System (GPS) receiver-processor. It will include 18 dual-frequency satellite channels and three distributed GPS antennae. The antennae will be oriented to provide full-sky coverage for precise orbit determination and Earth limb coverage for radio occultation measurements. GGI will serve four principal science objectives: 1) Cm-level global geodesy, 2) high-precision atmospheric temperature profiling, 3) ionospheric gravity wave detection and tomographic mapping, and 4) precise positioning in support of other science instruments. Positioning capability will help develop cm-level global geodesy and enhanced altimetry accuracies from companion instruments. Occultation tracking will provide several hundred daily atmospheric temperature profiles to better than 1K accuracy from 5 to 50 km, with better than 1-km resolution. Occultation measurements will also contribute to determination of global atmospheric energy balance and possible long-term trends. The flight instrument is derived from the GPS flight receiver developed for TOPEX/Poseidon, the U.S./French oceanographic mission scheduled for launch in 1992. ✩

FOR FURTHER INFORMATION:

Yunck, T., G.F. Lindal, and C.H. Liu, The role of GPS in precise Earth observation, *IEEE Position Location and Navigation Symposium*, Orlando, FL, November 1988.

GGI Parameters

Measurement Approach

Measures pseudo-range, carrier phase, and amplitude data from up to 18 GPS satellites using three antennae looking for ward, zenith, and aft; data from satellites are later combined with ground GPS receiver data to yield cm-level positioning
Swath: n/a
Spatial resolution: n/a

Accommodation Issues

Mass: 60 kg
Duty cycle: 100%
Power: 105 W
Data rate: 50 kbps
Thermal control by: Radiators
Thermal operating range: 10-20°C
FOV and Instrument IFOV: Hemispherical (zenith antenna) ±70° horizontal, +5 to -30° vertical (fore and aft antennae)
Pointing requirements (platform+instrument, 3σ):
Control: 3,600 arcsec
Knowledge: 123 arcsec
Stability: TBD
Jitter: TBD
Physical size: 8 x 12 x 20 in (electronics); 15-in diameter x 8 in (zenith antenna, to be deployed on 80-in boom in zenith direction); 5-in wide x 24-in tall (fore antenna, to be deployed on 120-in boom); 5-in wide x 24-in tall (aft antenna)

Antennae must be accommodated on booms; boom design may be difficult.
Final location of the Low Noise Amplifiers could impact boom/cable design.
Instrument is not contamination-sensitive; even so, the aft antenna may need to be located away from hydrazine thrusters.
Controlling multipath to the cm-level and providing sufficient antenna FOV may be complicated.

Principal Investigator—William G. Melbourne

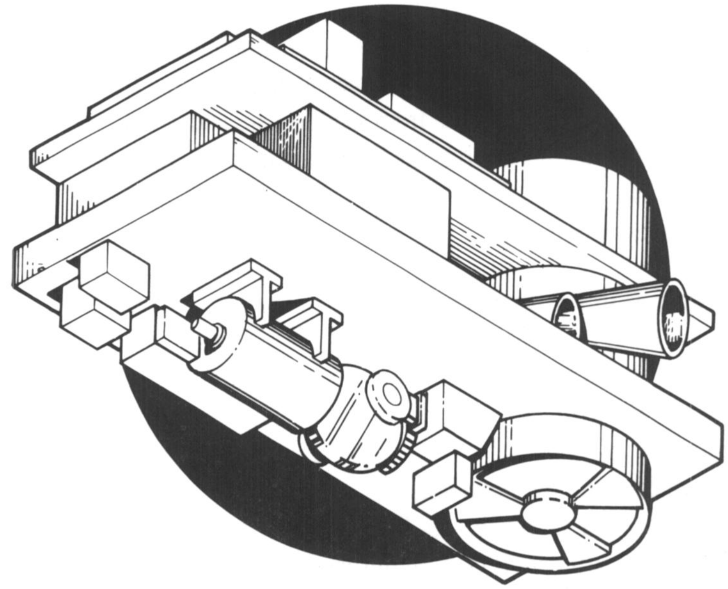
William Melbourne received an A.B. with highest honors in Astronomy-Physics from the University of California, Los Angeles, in 1954, and a Ph.D. in Astronomy from the California Institute of Technology in 1959. He joined the Jet Propulsion Laboratory (JPL) in 1956, and during the 1960s and 70s either served as major architect for, or directed the development of, numerous navigation and radio science systems and pioneered their application to geodynamics. Over the past 10 years, he has led NASA's program at JPL to develop a sub-decimeter-accuracy GPS-based tracking system for Earth-orbiting missions and a GPS-based geodetic system for centimeter-accuracy crustal deformation measurements. He is currently Assistant Division Manager for Metric Tracking in the Telecommunications Science and Engineering Division. He is also the Geodynamics Program Manager for the Office of Space Science and Instruments.

Co-Investigators

George H. Born, University of Colorado
Bradford H. Hager, California Institute of Technology
Gunnar F. Lindal, Jet Propulsion Laboratory
Chao-Han Liu, University of Illinois
Thomas K. Meehan, Jet Propulsion Laboratory
Thomas P. Yunck, Jet Propulsion Laboratory

GLRS

Geoscience Laser Ranging System



LASER RANGER AND ALTIMETER

HERITAGE: SATELLITE LASER RANGING SYSTEMS; AIRBORNE AND SPACEBORNE LASER ALTIMETRY AND LIDAR SYSTEMS

MEASURES CRUSTAL MOTION, ICE SHEET TOPOGRAPHY AND MOTION, CLOUD HEIGHTS, AND GEOLOGICAL PROCESSES AND FEATURES

GLRS is a laser ranger and altimeter designed to measure geodynamic, ice sheet, cloud, and geological processes and features. Crustal movements will be monitored using retroreflector targets on the Earth to detect strain accumulation in seismic zones and deformation near tectonic plate boundaries. Crustal motion near tide gauges will be measured in order to assess their contribution to apparent sea level change. The targets will be spaced by distances from a few km to several hundred km. Their intersite distances and relative heights will be determined to an accuracy of several mm. Repeated surveys will allow determination of relative velocities to an accuracy of a few mm/year over various time scales. The GLRS altimeter will measure range with an intrinsic precision of better than 10 cm. The altimeter has a 70-m ground spot diameter and will be used to measure ice sheet heights, slopes, and roughness characteristics. Changes in ice sheet thickness at a level of a few tens of cm, anticipated to occur on a subdecadal time scale, will be detected through orbital cross-over and banded track analyses. The ice sheet mass balance and ice sheet contribution to sea level change will also be determined. The accuracy of height determinations over land will be assessed using ground slope and roughness. The height distribution will be digitized over a total dynamic range of several tens of m. Along-track cloud and aerosol height distributions will be determined with a vertical resolution of 75 to 100 m from the surface to a height of 30 km. The horizontal resolution will vary from 150 m for dense cloud to 2 to 50 km for thin cloud. Planetary boundary heights, aerosol vertical structure, and stratospheric cloud structure will be determined with varying horizontal resolution; the cloud and aerosol backscatter cross sections will also be determined.

The GLRS laser is a frequency doubled and tripled, mode-locked, solid-state Nd:YAG laser with energy levels of 120 mJ (1,064 nm), 60 mJ (532 nm), and 40 mJ (355 nm). The pulse repetition rate is 40 pulses/sec, and the beam divergence is approximately 0.1 mrad. The green and ultraviolet pulses are used for two-color laser ranging, while the infrared pulse is used for altimetry. The ranger pointing system can be directed to 50° from nadir, both along-track and cross-track, and the receiving telescope has a diameter of 18 cm. The altimeter channel uses a 50-cm diameter telescope. ☆

FOR FURTHER INFORMATION:

Cohen, S.C., D.S. Chinn, and P.J. Dunn, Geoscience Laser Ranging System: Estimated accuracy of geodetic parameters and their dependence on system characteristics, *Journal of Geophysical Research, 95*, B12, 19,811-19,819, 1990.

GLRS Parameters

Measurement Approach

Uses Nd:YAG laser for surface and ice sheet topography measurements at 1.064 μm. Laser pulses are frequency doubled and tripled to 532 nm (green) and 355 nm (μV). The total time of flight of the 532 nm pulses and the difference between the 532 nm and the 355 nm pulses are measured to correct the atmospheric delay. The two-color measurements are used to determine baseline distances between retroreflecting targets on the Earth's surface for crustal dynamics investigations.

Swath: Capable of pointing ±50° along-track and cross-track (no scanning *per se*)
Spatial resolution: Laser footprint ~70 m at 1.064 μm

Accommodation Issues

Mass: 350 kg
Duty cycle: 50%
Power: 450 W (average), 660 W (peak)
Data rate: 400 kbps (average), 800 kbps (peak)
Thermal control by: Radiators
Thermal operating range: 15-25°C (TBD)
FOV: n/a
Instrument IFOV: ~70-m footprint at nadir at 1.064 μm
Pointing requirements (platform+instrument, 3σ):

Control:	90 arcsec (all axes, TBD)
Post-processing knowledge:	5 arcsec; 1 arcsec desired (all axes, to be provided by instrument-mounted star trackers)
Real-time knowledge:	10 arcsec
Stability:	TBD
Jitter:	TBD

Physical size: Approximately 1.5 x 1.5 x 0.95 m

Team Leader—Bob E. Schutz

Bob Schutz received a Ph.D. in 1969. Currently, he is Professor of Aerospace Engineering and Engineering Mechanics at the University of Texas at Austin, and holds the Gulf Oil Foundation Centennial Fellowship in Engineering. He is also Associate Director of the Center for Space Research and a member of the Applied Research Laboratory staff, both of which are components of the University of Texas at Austin.

Dr. Schutz is active in research pertaining to the application of satellite data to the areas of geodesy, geophysics, and oceanography. He has extensive experience in the analysis of laser ranging measurements from LAGEOS and other satellites, radar altimeter measurements collected from Seasat and Geosat, and measurements obtained from the Global Positioning System. He has been instrumental in the development of software for studies in crustal motions, sea surface topography, orbital dynamics, variations in Earth rotation, and temporal changes in the Earth gravity field.

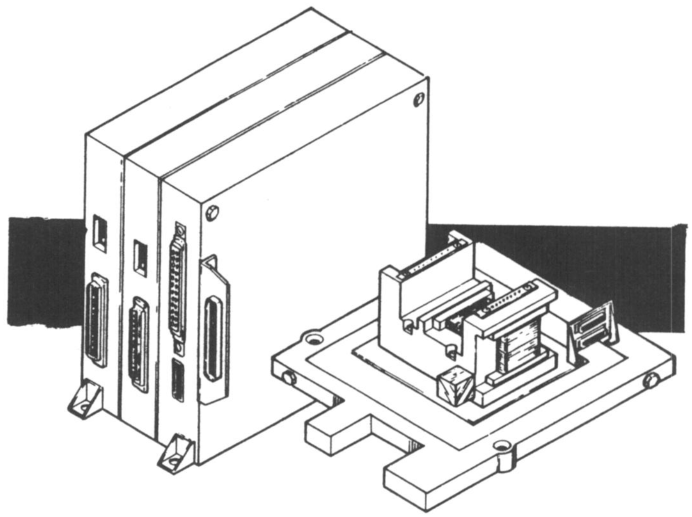
Dr. Schutz serves as the Satellite Laser Ranging Coordinator of the International Earth Rotation Service and as chairman of the Subcommission on Satellite Laser Ranging. He is a member of the IAU Commission 19, Secretary of the International Association of Geodesy Section 2, a former Associate Editor of the AGU's EOS, and current Associate Editor of Journal of the Astronautical Sciences.

Team Members

Charles R. Bentley, University of Wisconsin
Michael G. Bevis, North Carolina State University
Jack L. Bufton, Goddard Space Flight Center
Steven Cohen, Goddard Space Flight Center
Thomas A. Herring, Massachusetts Institute of Technology
Kim A. Kastens, Lamont-Doherty Geological Observatory
Jean-Bernard Minster, Scripps Institution of Oceanography
William H. Prescott, U.S. Geological Survey
Robert E. Reilinger, Massachusetts Institute of Technology
James D. Spinhirne, Goddard Space Flight Center
Robert H. Thomas, Universities Space Research Association
H. Jay Zwally, Goddard Space Flight Center

GOS

Geomagnetic Observing System



BOOM-MOUNTED VECTOR FLUXGATE MAGNETOMETER; SCALAR-HELIUM MAGNETOMETER

HERITAGE: MAGSAT, ISEE-3/ICE

MEASURES THE EARTH'S MAGNETIC FIELD: OBTAINS ABSOLUTE SCALAR FIELDS AT ±1-NANOTESLA ACCURACY; VECTOR FIELDS AT ±3-NANOTESLA PER AXIS, ROOT SUM SQUARE

THREE STAR TRACKERS PROVIDE POINTING KNOWLEDGE

TWO ORTHOGONAL SCALAR MAGNETOMETERS/TRI-AXIAL VECTOR MAGNETOMETER MOUNTED AT END OF 25-M BOOM

The magnetic field of the Earth will be measured by a three-axis fluxgate and a scalar helium magnetometer. Measurement accuracy goals are 2.0 nT root sum square (rss) for the scalar magnitude and 5.0 nT rss for each component. The magnetometers, together with non-magnetic star trackers, will be mounted on an optical platform at the end of a boom. The data will be used both to study the Earth's interior and the electrodynamic ionosphere-magnetosphere coupling. Specific scientific objectives involve accurately modeling the magnetic field and its temporal change; studying core fluid dynamics; studying correlation with length-of-day changes; studying mantle conductivity; measuring characteristics and generation mechanisms of field-aligned and ionospheric currents; investigating dynamics and energetics of the high-latitude ionosphere; and, together with other spacecraft, performing a multi-point investigation of the large-scale structure and dynamics of the auroral regions. ☆

FOR FURTHER INFORMATION:

Mobley, F.F., *et al.*, Magsat: A new satellite to survey the Earth's magnetic field, *IEEE Transactions on Magnetics*, *16*, 758-760, 1980.

GOS Parameters

Measurement Approach
Swath: n/a
Spatial resolution: n/a

Accommodation Issues
Mass: 96.1 kg
Duty cycle: 100%
Power: 67.3 W
Data rate: 20 kbps
Thermal control by: Radiators, heaters
Thermal operating range:
- 34-35°C (vector magnetometer)
- -30 to +40°C (plasma wave sensors)
- -10 to +40°C (electronics)

FOV (star trackers): ±50° (in x-direction) by +30 to -10° (in z-direction); each star tracker (3 or 4) needs 10 x 10° FOV around its boresight

Instrument IFOV: n/a
Pointing requirements (star trackers, 1σ):

Control:	none
Knowledge:	±10 arcsec
Stability:	n/a
Jitter:	n/a

Physical size (stowed): 0.8 x 1.6 x 0.3 m
Physical size (deployed): 0.24 x 0.65 x 0.29 m (electronics)
- 0.29 m diameter x 1 m (boom canister)
- 1 x 0.25 x 0.05 m (star trackers, at end of 25-m boom in +x direction)
- Two sets of three 10-m tubes (centered at 7 m and 17 m along boom from leading edge of platform)

Star trackers are deployed into the velocity (+x) direction at the end of an 18- to 25-m boom.

Principal Investigator—Robert Langel III

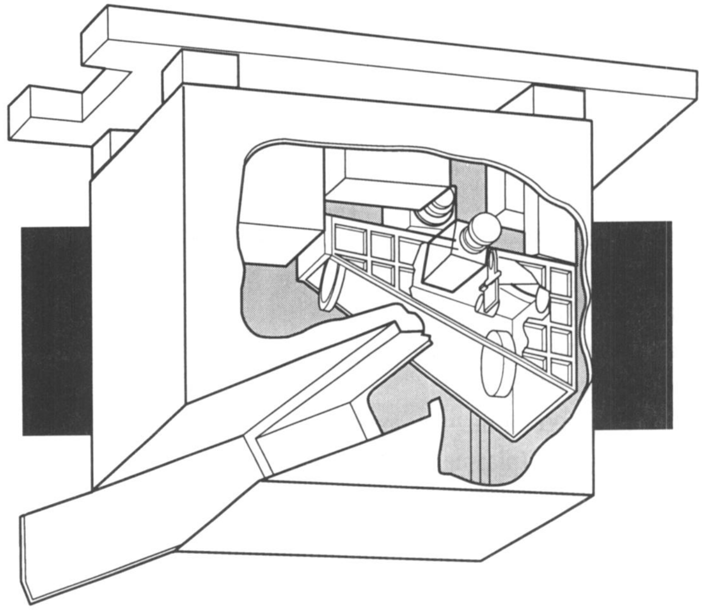
Dr. Langel has a Ph.D. in Physics, and has studied the Earth's magnetic field since the mid-1960s. He has been a pioneer in the development of magnetic field modeling methods and has written a definitive work on main-field modeling. He has been associated with Goddard Space Flight Center since 1963, at present with the Geodynamics Branch. He was part of the magnetometer team for the Polar-Orbiting Geophysical Observatory (POGO) spacecraft, was project scientist for Magsat, and is NASA study scientist for ARISTOTELES and MFE/Magnolia. He was recipient of the NASA Exceptional Scientific Achievement Medal, was a Visiting Scholar at Cambridge University in 1983-84, and is a Fellow of the American Geophysical Union.

Co-Investigators

Jose J. Achache, Institut de Physique du Globe de Paris
Mario H. Acuna, Goddard Space Flight Center
George E. Backus, University of California, San Diego
David R. Barraclough, British Geological Survey
Edward R. Benton, University of Colorado
Peter F. Bythrow, The Johns Hopkins University
Karl-Heinz Glassmeier, Universitat Koln
John F. Hermance, Brown University
Yahsuke Kamide, Kyoto Sangyo University
Jean Louis LeMouel, Institut de Physique du Globe de Paris
Norman W. Peddie, U.S. Geological Survey
Thomas A. Potemra, The Johns Hopkins University
F. Rich, Air Force Geophysics Laboratory
James A. Slavin, Goddard Space Flight Center
Edward J. Smith, Jet Propulsion Laboratory
Masahisa Sugiura, Geophysical Institute
Bruce T. Tsurutani, Jet Propulsion Laboratory
Coerte Voorhies, Goddard Space Flight Center
Daniel Winterhalter, Jet Propulsion Laboratory
Takesi Yukutake, The University of Tokyo
Lawrence J. Zanetti, John Hopkins University

HIRDLS

High-Resolution Dynamics Limb Sounder



OBSERVES GLOBAL DISTRIBUTION OF TEMPERATURE AND CONCENTRATIONS OF O_3, H_2O, CH_4, N_2O, NO_2, HNO_3, N_2O_5, CFC_{11}, CFC_{12}, $ClONO_2$, AND AEROSOLS IN THE UPPER TROPOSPHERE, STRATOSPHERE, AND MESOSPHERE

SPECTRAL RANGE 6 TO 18 μM

STANDARD PROFILE SPACING 4° LONGITUDE x 4° LATITUDE, AND 1-KM VERTICAL RESOLUTION; PROGRAMMABLE TO OTHER MODES AND RESOLUTION

FORE-OPTICS BASED ON UARS ISAMS AND FOCAL PLANE BASED ON NIMBUS-7 LIMS

OTHER HERITAGE: NIMBUS-4,5,6 AND UARS

HIRDLS is an infrared limb-scanning radiometer designed to sound the upper troposphere, stratosphere, and mesosphere to determine temperature; the concentrations of O_3, H_2O, CH_4, N_2O, NO_2, HNO_3, N_2O_5, CFC_{11}, CFC_{12}, $ClONO_2$, and aerosols; and the locations of polar stratospheric clouds and cloud tops. The goals are to make observations with horizontal and vertical resolution superior to that previously obtained, to observe the lower stratosphere with improved sensitivity and accuracy, and to use the data to improve understanding of atmospheric processes through data analysis, diagnostics, and use of 2- and 3-D models.

HIRDLS performs limb scans in the vertical at multiple azimuth angles, measuring infrared emissions in 21 channels ranging from 563 to 1,990 cm^{-1}. Four channels measure the emission by CO_2. Taking advantage of the known mixing ratio of CO_2, the transmittance is calculated, and the equation of radiative transfer is inverted to determine the vertical distribution of the Planck black body function, from which the temperature is derived as a function of pressure. Once the temperature profile has been established, it is used to determine the Planck function profile for the trace gas channels. The measured radiance and the Planck function profile are then used to determine the transmittance of each trace species and its mixing ratio distribution.

Winds and potential vorticity are determined from spatial variations of the height of geopotential surfaces. These are determined at upper levels by integrating the temperature profiles up from a known reference base. HIRDLS will improve over conventional data in data-sparse regions by measuring the height variations of this reference surface with the aid of a gyro package. This level, near the base of the stratosphere, can also be integrated downward using nadir temperature soundings to improve tropospheric analyses.

The instrument has a long heritage extending back to Nimbus-4, and will obtain profiles over the entire globe, including the poles, by day and night. High horizontal resolution is obtained with a commandable azimuth scan which, in conjunction with a rapid elevation scan, provides a 2,000- to 3,000-km-wide swath of profiles along the satellite track. Observations of the lower stratosphere are improved through the use of special narrow and more transparent spectral channels. The instrument is programmable; thus, a variety of observation modes can be used, and may be adapted in flight to observe unexpected geophysical events. ☆

FOR FURTHER INFORMATION:
Gille, J., The High-Resolution Dynamics Limb Sounder (HIRDLS), in *The Use of EOS to Study Atmospheric Physics*, North Holland, 1991.

HIRDLS Parameters

Measurement Approach
Scanning infrared limb sounder
21 photo-conductive HgCdTe detectors cooled to 80K

Swath: Typically six profiles across 2,000- to 3,000-km-wide swath (programmable)
Spatial resolution: Profile spacing 400 x 400 km horizontally (equivalent to 4° long x 4° lat) x 1 km vertically; averaging volume for each data sample 1 km vertical x 10 km cross x 400 km along line-of-sight

Accommodation Issues
Mass: 150 kg
Duty cycle: 100%
Power: 150 W (average), 200 W (peak)
Data rate: 40 kbps
Thermal control by: Paired 80K Stirling cycle coolers, central thermal bus, heaters, sun baffle
Thermal operating range: 20-30°C
FOV (scan range): elevation, ±2.5° about -25.3° below horizontal; azimuth, -20° (sunside) to +50° (anti-sun side)
Detector IFOV: 1 km vertical x 10 km horizontal
Pointing requirements (platform+instrument, 3σ):
Control: 360 arcsec (all axes)
Knowledge: 180 arcsec (all axes)
Stability: 180 arcsec (roll and pitch), 360 arcsec (yaw)
Jitter (>1 Hz): 1 arcsec (roll and pitch), 5 arcsec (yaw)
Physical size: 1.092 x 0.774 x 1.119 m; TBD sunshield extension to be deployed

Co-Principal Investigators—John Barnett and John Gille

Dr. Barnett received an M.A. in Natural Sciences, with first class honors, from Cambridge University and a Ph.D. in Atmospheric Physics from Oxford University. He is currently a University Research Lecturer for the Department of Physics at Oxford. Dr. Barnett served as a member of data processing teams for the suite of Nimbus instruments, as Co-Investigator for Improved Stratospheric and Mesospheric Sounder (ISAMS), and as co-chairman of the COSPAR group on the Reference Middle Atmosphere. He is the recipient of the COSPAR William Nordberg Award and the Royal Meteorological Society L.F. Richardson Award.

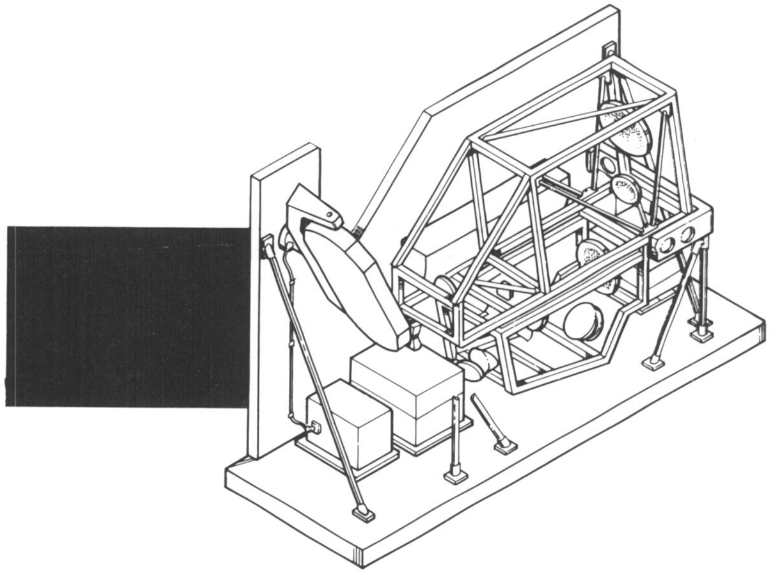
John Gille received a B.S. in Physics, magna cum laude, from Yale University, an M.A. in Physics from Cambridge University, and a Ph.D. in Geophysics from MIT. Since 1977, he has served as Head of the Global Observations, Modeling, and Optical Techniques Section of NCAR. Dr. Gille was Co-Sensor Scientist on LIMS, launched on Nimbus-7 in 1978, and was Principal Investigator on LRIR, which flew on Nimbus-6 in 1975. He has been involved in CLAES collaboration since 1982, with NOAA's development of GOMR, and on several investigations analyzing satellite data. He is a Fellow of the American Meteorological Society and the American Association for the Advancement of Science, and was the recipient of the NCAR Technology Advancement Award in 1978 and the NASA Exceptional Scientific Achievement Medal in 1982.

Co-Investigators

David Andrews, Oxford University
Paul Bailey, National Center for Atmospheric Research
Byron Boville, National Center for Atmospheric Research
Guy Brasseur, National Center for Atmospheric Research
Michael Coffey, National Center for Atmospheric Research
Robert S. Harwood, University of Edinburgh
James R. Holton, University of Washington
Conway B. Leovy, University of Washington
William Mankin, National Center for Atmospheric Research
Michael E. McIntyre, University of Cambridge
Heinz G. Muller, University of Sheffield
Christopher T. Mutlow, Rutherford Appleton Laboratory
Alan O'Neill, British Meteorological Office
John Adrian Pyle, University of Cambridge
Clive D. Rodgers, Oxford University
John Seeley, University of Reading
Frederic Taylor, Oxford University
Geraint Vaughan, University College of Wales
Robert J. Wells, Oxford University
Stephen T. Werrett, Oxford University
John G. Whitney, Oxford University
E.J. Williamson, Oxford University

HIRIS

High-Resolution Imaging Spectrometer



HERITAGE: AIS I AND II, AVIRIS

PROVIDES HIGH SPECTRAL AND SPATIAL RESOLUTION IMAGES OF THE EARTH

CAN SAMPLE ANY POINT ON THE EARTH'S SURFACE A MINIMUM OF EVERY 2 DAYS

HIRIS is an imaging spectrometer facility instrument that provides both high spectral and spatial resolution images of the Earth, and that can sample any point on the surface at a minimum of every 2 days. HIRIS employs a pointable imaging spectrometer with area array detectors. Reflected solar energy from the target passes through the optical system—consisting of the pointing mirror, objective lens, entrance slit, collimator, dispersing element, and imaging optics—then arrives at the area array. The instrument covers the 0.4- to 2.45-µm wavelength region in 192 spectral bands with 10-nm spectral sampling and 30-m pixel size. The swath width is 24 km.

The HIRIS spectral range covers almost all the solar radiation reflected from the Earth's surface, and many diagnostic and/or characteristic reflectance features of terrestrial targets are found within this region. The instrument's 10-nm spectral sampling allows for biological studies in the visible and near-infrared, and for mineralogical mapping in the shortwave infrared. Cross-track pointing permits frequent repeat sampling. Along-track pointing will be used to estimate the bidirectional reflectance distribution function of surfaces, to remove atmospheric attenuation, and to implement image-motion compensation to increase signal-to-noise ratio for dark targets. Contiguous spectral coverage will be used to perform spectral analyses.

HIRIS operates at the intermediate scale between the human and the global, thus is essential in linking the studies of processes at the surface of the Earth to EOS. Some of the fundamental questions in Earth system science revolve around the scale dependence of many processes (and scale invariance in others), along with the interactions of processes that occur at fundamentally different scales.

Over land, HIRIS data will be used to retrieve many products related to vegetation, including chlorophyll concentration, leaf area index, leaf tissue water content, canopy composition and geometry, vegetation indices, and the distributions of dead and green biomass. Other HIRIS products over land will include relative abundances of Fe-, CO_3-, SO_4-, and OH-containing minerals; snow distribution and characteristics; surface temperature and extent of volcanic activity; and absorbed photosynthetic radiation.

Over oceans, HIRIS products will include gelbstoff absorption coefficients, chlorophyll concentration and accessory pigment measurements, and backscattering coefficients. HIRIS atmospheric products will include several cloud characteristics, as well as aerosol optical depth, total precipitable water, and total column ozone. ☆

FOR FURTHER INFORMATION:

Dozier, J. and A.F.H. Goetz, HIRIS—EOS instrument with high spectral and spatial resolution, *Photogrammetria, 43*, 3/4, 167-180, 1989.

HIRIS Parameters

Measurement Approach

Targets the image area of interest by pointing line-of-sight from +56 to -30° along-track (positive is in velocity direction) and ±45° cross-track

Imaging spectrometer measures the radiance of reflected light from 0.40 to 2.45 μm dispersed into 192 spectral channels; contigious samples are approximately 10-nm wide

Swath: 24 km (800 pixels)
Spatial resolution: 30 m at nadir

Accommodation Issues

Mass: 450 kg
Duty cycle: 3% (long-term average)
Power: 300 W (average), 600 W (peak)
Data rate: 3 Mbps (long-term average)
100 Mbps (peak to platform)
405 Mbps (internal to instrument)
Thermal control by: Central thermal bus, radiator
Thermal operating range: 0-40°C (electronics), 270K (optics), 130K (detector)
FOV: Approximately 2° at nadir (800 IFOVs cross-track)
Instrument IFOV: 8.8 x 8.8 arcsec pixels
Pointing requirements (platform+instrument, 3σ):

Control:	±293 arcsec, ±1 km at nadir
Knowledge:	±117 arcsec, ±400 m
Stability:	1.08 arcsec peak-to-peak per sec
Jitter:	7.2 arcsec peak-to-peak per 1,000 sec

Physical size: 0.86 x 0.33 x 0.86 m (electronics)
2.62 x 1.00 x 1.20 m (additional module, stowed)
2.62 x 1.00 x 1.92 m (additional module, deployed)

Team Leader—Alexander Goetz

Alexander Goetz holds degrees in Physics, Geology, and Planetary Science from the California Institute of Technology; from 1970 to 1985, Dr. Goetz was affiliated with that institution's Jet Propulsion Laboratory (JPL). Presently, he is a Professor in the Department of Geological Sciences and Director of the Center for the Study of Earth from Space at the University of Colorado. His current interests include applying remote sensing techniques to a wide range of scientific disciplines, including geology, hydrology, ecology, and atmospheric science. He also develops new instrumentation for field application of remote sensing techniques.

Dr. Goetz has spent over 20 years as a Principal Investigator for flight instruments and data analysis projects in various NASA programs, including Apollo, Landsat 1, Skylab, and the Space Shuttle. He served as JPL's Imaging Spectrometer Program Manager for 2 years and, as such, developed the concepts for the airborne and spaceborne imaging spectrometers. He was the Principal Investigator for the Shuttle Imaging Spectrometer Experiment, which, although it did not fly, formed the basis for the HIRIS concept. From 1984 to 1987, he chaired the Imaging Spectrometer Science Advisory Group, which developed the requirements for SISEX and HIRIS.

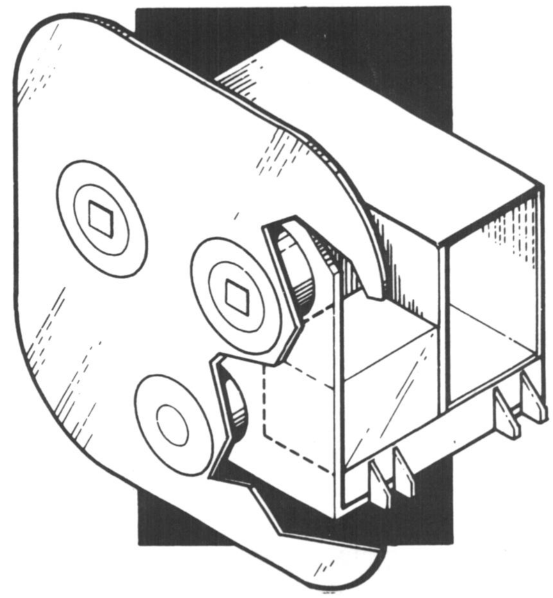
Dr. Goetz's other activities mirror these interests. In addition to being well-published in the current literature, he serves on several advisory boards for the National Research Council; has consulted with private industry both in the U.S. and abroad; has taught an independent short course in advanced remote sensing for geologists and geophysicists; holds four spectral instrument patents; is an associate editor for two journals; and has received numerous performance and special achievement awards.

Team Members

John Aber, University of New Hampshire
Kendall L. Carder, University of South Florida
Roger Nelson Clark, U.S. Geological Survey
Curtiss O. Davis, Jet Propulsion Laboratory
Jeff Dozier, University of California, Santa Barbara
Siegfried Gerstl, Los Alamos National Laboratory
Hugh H. Kieffer, U.S. Geological Survey
David A. Landgrebe, Purdue University
John M. Melack, University of California, Santa Barbara
Lawrence C. Rowan, U.S. Geological Survey
Susan L. Ustin, University of California, Davis
Ronald Welch, South Dakota School of Mines & Technology
Carol A. Wessman, University of Colorado

IPEI

Ionospheric Plasma and Electrodynamics Instrument



RETARDING POTENTIAL MASS ANALYZER AND ION DRIFT METER

HERITAGE: AE AND DE

DETERMINES THERMAL ENERGY DISTRIBUTION AND THERMAL ION ARRIVAL ANGLE WITH RESPECT TO SPACECRAFT VELOCITY

DETERMINES RELATIVE ABUNDANCE OF IONOSPHERIC CONSTITUENTS H^+, He^+, AND O^+

ION DRIFT IS MEASURED FROM 10 TO 5,000 M/SEC IN THREE DIRECTIONS, CONCENTRATIONS FROM 1.5×10^6 CM^{-3}, AND TEMPERATURES FROM 200 TO 20,000K

IPEI will measure thermal ion and electron temperatures, ion composition, and ion dynamics in the ionosphere. These measurements sense electric fields generated by motion of neutral gas in the lower atmosphere, by the magnetosphere, and by thundertorms in the troposphere. The measurements will also monitor the energy transport and conversion processes that take place as a result of interactions between the charged and neutral particles. Questions pertaining to the global electric circuit, energy dissipation during solar disturbances, and the transport of plasma from low to high altitudes will be addressed using data from IPEI.

IPEI products will include the horizontal and vertical components of ion drift velocity with 5 percent accuracy, bulk ion temperature with 8 percent accuracy, ion concentrations with 2 percent accuracy, and electron temperatures with 5 percent accuracy. The resolution of these measurements will be 0.1° in latitude and 22° in longitude. ☆

FOR FURTHER INFORMATION:

Heelis, R.A.., W.B. Hanson, C.R Lippincott, D.R. Zucarro, L.H. Harmon, B.J. Hotop, J.E. Doherty, and R.A. Power, The ion drift meter for Dynamics Explorer, *Space Science Instrumentation*, *5*, 511-521, 1981.

IPEI Parameters

Measurement Approach

In situ ion composition, ion drift detection, and ion and electron temperature; composed of two ion drift meters, a retarding potential mass analyzer, and a Langmuir probe

Swath: n/a (looks ram, never at Earth)
Spatial resolution: n/a

Accommodation Issues

Mass: 12 kg + mounting pedestal + arm and platform mounting and deployment components for Langmuir probe sensors
Duty cycle: 100%
Power: 10 W
Data rate: 1.1 kbps
Thermal control by: Radiator
Thermal operating range: -10 to +50°C

FOV: ±45° cone in ram
Instrument IFOV: n/a
Pointing requirements (platform+instrument, 3σ):

Control:	18,000 arcsec (sensors) 1,800 arcsec (main package)
Knowledge:	18,000 arcsec (sensors) 360 arcsec (main package)
Stability:	18,000 arcsec per min (sensors) 3,600 arcsec per min (main package)
Jitter:	3,600 arcsec per sec (sensors) 360 arcsec per sec (main package)
Physical size:	25 x 41 x 39 cm (main package) TBD pedestal 5 cm diameter x 0.2 cm thick disk and 0.5 cm diameter x 10 cm long cylinder deployed at end of 130-cm boom (Langmuir probe, stowed size TBD)

Principal Investigator—Roderick Heelis

Academically trained in Applied Mathematics, Roderick Heelis has concentrated his professional career in planetary ionospheres and magnetospheres, and the physical phenomena coupling these regions. He has been affiliated with the University of Texas at Dallas, Center for Space Sciences, for the last 17 years; since 1986, he has served as Associate Director. He is a member of the Dynamics Explorer Flight Team and has served as member or chair of numerous committees concerned with space physics. He is well-published in the field, and is a past Associate Editor of the *Journal of Geophysical Research*, receiving that publication's Citation for Excellence in Refereeing. Dr. Heelis is also listed in American Men and Women of Science.

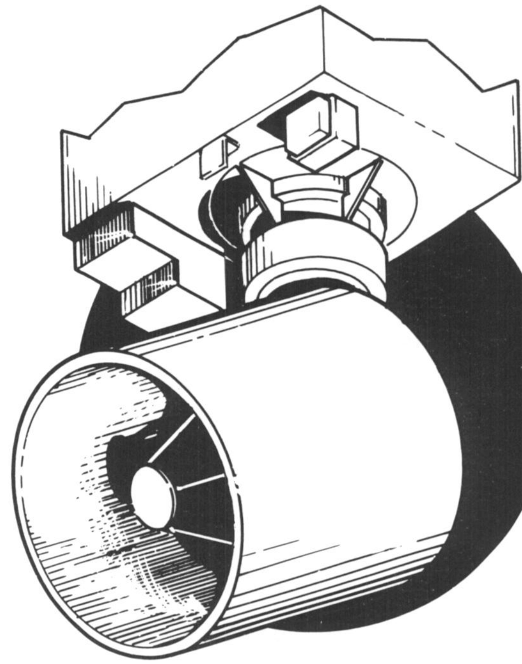
Co-Investigators

W.B. Hanson, University of Texas at Dallas

John H. Hoffman, University of Texas at Dallas

LAWS

Laser Atmospheric Wind Sounder



DOPPLER LIDAR SYSTEM

HERITAGE: GROUND, AIRCRAFT, AND DESIGN STUDIES

DIRECTLY MEASURES TROPOSPHERIC WINDS

PROVIDES DISTRIBUTION OF AEROSOLS AND CIRRUS CLOUDS

PROVIDES HEIGHT OF CIRRUS AND STRATIFORM CLOUDS

LAWS is a Doppler lidar system for direct tropospheric wind measurements. The global wind profiles from LAWS will be fundamental in advancing knowledge of the Earth as a system. The key EOS objectives that LAWS data will help meet include determining what factors control the hydrologic cycle (specifically, a more accurate estimate of the horizontal transport of water vapor can be determined and, through the use of LAWS winds in global models with 4-D data assimilation systems, the depiction of vertical motion and precipitation will be improved); quantifying the global distribution and transport of tropospheric gases and aerosols; determining the relationships between the large-scale, low-frequency variability of meteorological fields; improving the accuracy of deterministic weather forecasting; and determining the global heat, mass, and momentum coupling between the ocean and atmosphere. Fluxes of momentum, heat, moisture, CO_2, and other constituents are important to a majority of the EOS interdisciplinary studies, and are currently parameterized with respect to mean horizontal winds in the boundary layer. LAWS will provide complementary data to the scatterometer over water, which should significantly improve knowledge of these fluxes.

In addition to profiles of the horizontal wind, LAWS will provide the distribution of aerosols (sampled at 9.11 µm wavelength) and cirrus clouds, and the heights of cirrus and stratiform clouds. ☆

FOR FURTHER INFORMATION:

Baker, W.E., Wind measurements expected with the Laser Atmospheric Wind Sounder, in *Seventh Symposium on Meteorological Observations and Instrumentation,* 169-174, AMS, Boston, 1991.

LAWS Parameters

Measurement Approach

Coherent Doppler lidar using a pulsed, frequency-controlled CO_2 laser transmitter operating at 9.11 µm, a continuously scanning transmit and receive telescope, a heterodyne detector, and a signal processing system

Swath: 1,050 km at 525-km altitude

Spatial resolution: 100 x 100 km horizontal, 1 km vertical (300 m in high aerosol regions)

Altitude range: 500-650 km

Accommodation Issues

Mass: 800 kg
Duty cycle: 100%
Power: 2,200 W (average), TBD (peak)
Pulse energy: Minimum 15 J/pulse in the far field
Pulse length: 2.5-3.5 μsec
Receiver bandwidth: ~1.3 GHz
Average laser pulse repetition frequency (PRF): Capability to sustain 10 Hz PRF average per telescope scan, but constrained by the average power per orbit
Laser wallplug efficiency: >5%
Minimum shot density: 6 pulses (3 pulse pairs) per 100^2 km^2 grid in the same orbit with a vertical resolution of 1 km (assuming 5 Hz PRF at 525 km)
Laser lifetime: 10^9 shots over 5 years
Line-of-sight velocity error: System contribution will not exceed 1.0 $msec^{-1}$

Data rate: 2 Mbps (average), 10 Mbps (peak)
Thermal control by: Stirling cycle cooler, central thermal bus, radiators, heaters, multi-layer insulation
Thermal operating range: TBD
FOV: Telescope scans conically at 45° to nadir
Instrument IFOV: TBD
Telescope scan rate: 6-12 rpm
Platform performance capabilities (3σ per axis):

	Navigation Base	Inst. Interface
Attitude knowledge:	36 arcsec	108 arcsec
Attitude accuracy:	108 arcsec	150 arcsec
Altitude knowledge:	100 m	100 m
Stability:	7.2 arcsec/10^3 sec	TBD
Jitter:	1 arcsec/sec	TBD

Physical size: 1.6-m diameter telescope

Team Leader—Wayman Baker

Wayman Baker is Deputy Chief of the Development Division at NOAA's National Meteorological Center. Blending academic skills in Mathematics and the Atmospheric Sciences (Ph.D. from the University of Missouri, 1978) and professional experience as a meteorologist, he has focused his scientific research on atmospheric dynamics, general circulation, and numerical weather prediction.

Dr. Baker is thoroughly familiar with the LAWS instrument. In 1985, he organized and co-chaired the NASA Symposium and Workshop on Global Wind Measurements, in which more than 100 meteorologists and instrument technologists participated. The recommendations that resulted from the workshop contributed significantly to the selection of LAWS as one of the NASA research facility instruments, and helped put the development of the necessary technology on a well-defined path. Since then, he has continued his involvement in a wide range of activities relevant to the LAWS instrument.

In addition to his work with LAWS, Dr. Baker has contributed often to refereed publications and many technical reports and papers, and frequently serves as a reviewer of proposals for NSF, NASA, and NOAA. Dr. Baker has received several citations and awards—including a NASA Special Achievement Award in 1983, the NASA/Goddard Laboratory for Atmospheres Scientific Research Award in 1986, and a NOAA Performance Award in 1989—and was elected a Fellow of the American Meteorological Society in 1989.

Team Members

John R. Anderson, University of Wisconsin
Robert M. Atlas, Goddard Space Flight Center
Robert A. Brown, University of Washington
George Emmitt, Simpson Weather Associates, Inc.
Dan Fitzjarrald, Marshall Space Flight Center
R. Michael Hardesty, NOAA/ERL/WPL
T.N. Krishnamurti, Florida State University
Andrew Lorenc, Meteorological Office
Robert Menzies, Jet Propulsion Laboratory
Timothy L. Miller, Marshall Space Flight Center
John Molinari, State University of New York
Jan Paegle, University of Utah
Madison Post, NOAA/ERL/WPL

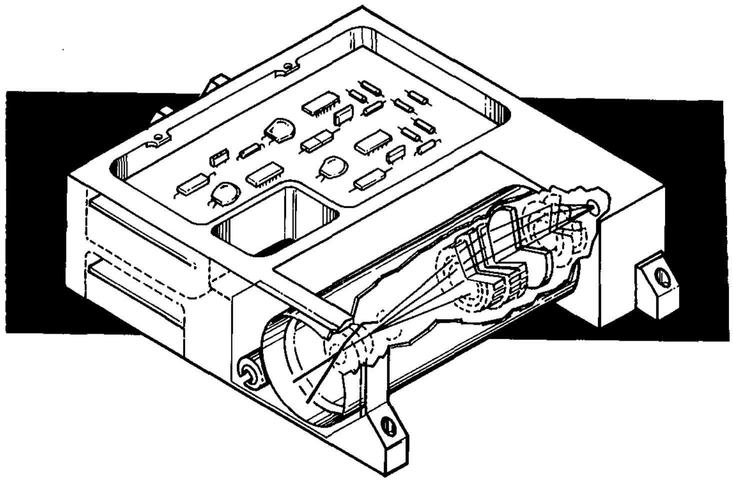
Associate Member

David Bowdle, University of Alabama

LIS

Lightning

Imaging Sensor



STARING TELESCOPE/FILTER IMAGING SYSTEM

UNDER DEVELOPMENT FOR GEOSTATIONARY ORBIT; FLOWN ON NASA AIRCRAFT

ACQUIRES AND INVESTIGATES THE DISTRIBUTION AND VARIABILITY OF LIGHTNING OVER THE EARTH

90% DETECTION EFFICIENCY UNDER BOTH DAY AND NIGHT CONDITIONS USING BACKGROUND REMOVER AND EVENT PROCESSOR

STORM-SCALE (10-KM) SPATIAL RESOLUTION; 1-MSEC TEMPORAL RESOLUTION

ALSO A CANDIDATE FOR TRMM AND A SATELLITE OF OPPORTUNITY

The calibrated optical LIS will investigate the global incidence of lightning, its correlation with rainfall, and its relationship with the global electric circuit. Conceptually, LIS is a simple device, consisting of a staring imager optimized to detect and to locate both intracloud and cloud-to-ground lightning with storm-scale resolution over a large region of the Earth's surface, to mark the time of occurrence, and to measure the radiant energy. It will monitor individual storms within the field-of-view (FOV) for 2 minutes, long enough to estimate the lightning flashing rate. Location of lightning flashes will be determined to within 8.5 km over an 1,100-km^2 FOV.

The LIS design uses an expanded optics wide-FOV lens, combined with a narrow-band interference filter focusing the image on a small, high-speed, charged coupled device (CCD) focal plane. The signal is read out from the focal plane into a real-time data processor for event detection and data compression. The particular characteristics of the sensor design result from the requirement to detect weak lightning signals during the day when the background illumination, produced by sunlight reflecting from the tops of clouds, is much brighter than the illumination produced by the lightning.

A combination of four methods is used to take advantage of the significant differences in the temporal, spatial, and spectral characteristics between the lightning signal and the background noise. First, spatial filtering is used to match the instantaneous FOV of each detector element in the LIS focal plane array to the typical cloud-top area illuminated by a lightning event (about 10 km). Second, spectral filtering is applied, using a narrow-band interference filter centered on a strong optical emission line, OI(1) at 777.4 nm, in the lightning spectrum. Third, temporal filtering is applied. The lightning pulse duration is of the order of 400 µsec, whereas the background illumination tends to be constant on a time scale of seconds. The lightning signal-to-noise ratio improves as the integration time approaches the pulse duration. Accordingly, an integration time of 2 msec is chosen, to minimize pulse splitting between successive frames and to maximize lightning detectability. Finally, a modified frame-to-frame background subtraction is used to remove the slowly varying background signal from the raw data coming off the LIS focal plane. If, after background removal, the signal for a given pixel exceeds a specified threshold, that pixel is considered to contain a lightning event.

LIS investigations will further understanding of processes related to, and underlying, lightning phenomena in the Earth/atmosphere system. These processes include the amount, distribution, and structure of deep convection on a global scale, and the coupling between atmospheric dynamics and energetics as related to the global distribution of lightning activity. The investigations will contribute to several important EOS mission objectives, including cloud characterization and hydrologic cycle studies. Lightning activity is closely coupled to storm convection, dynamics, and microphysics, and can be correlated to the global rates, amounts, and distribution of precipitation, to the release and transport of latent heat, and to the chemical cycles of carbon, sulfur, and nitrogen. ☆

FOR FURTHER INFORMATION:

Christian, H.J., R.J. Blakeslee, and S.J. Goodman, The detection of lightning from geostationary orbit, *Journal of Geophysical Research*, vol. 94, 13,329-13,337, 1989.

LIS Parameters

Measurement Approach

Staring imager that detects the rate, position, and radiant energy of lightning flashes

Spectral filter to image at 777.4 nm onto a 128 x 128 CCD array detector

Event processor to subtract out the bright background during daylight (instrument taking data day and night)

Swath: 1,100 x 1,100 km

Spatial resolution: 8.5 km

Accommodation Issues

Mass: 15 kg

Duty cycle: 100%

Power: 33 W

Data rate: 6 kbps

Thermal control by: Heater, radiator

Thermal operating range: 0-40°C

FOV: 75 x 75°

Instrument IFOV: 0.7°

Pointing requirements (platform+instrument, 3σ):

Control:	None
Knowledge:	1 km on ground
Stability:	TBD
Jitter:	TBD

Physical size: 0.3 x 0.2 x 0.3 m

Principal Investigator—Hugh Christian

Hugh Christian is a graduate of the University of Alaska, and received an M.S. and Ph.D. in Space Physics and Astronomy from Rice University. He has served in various government, private industry, and academic capacities, primarily within his area of expertise: Thunderstorms, atmospheric electricity, lightning data acquisition systems, and airborne instrumentation. Since 1980, Dr. Christian has been a Space Scientist at the Marshall Space Flight Center. In conjunction with his research, he has published numerous articles, has served as presenter at related conferences, and served on many scientific committees.

Co-Investigators

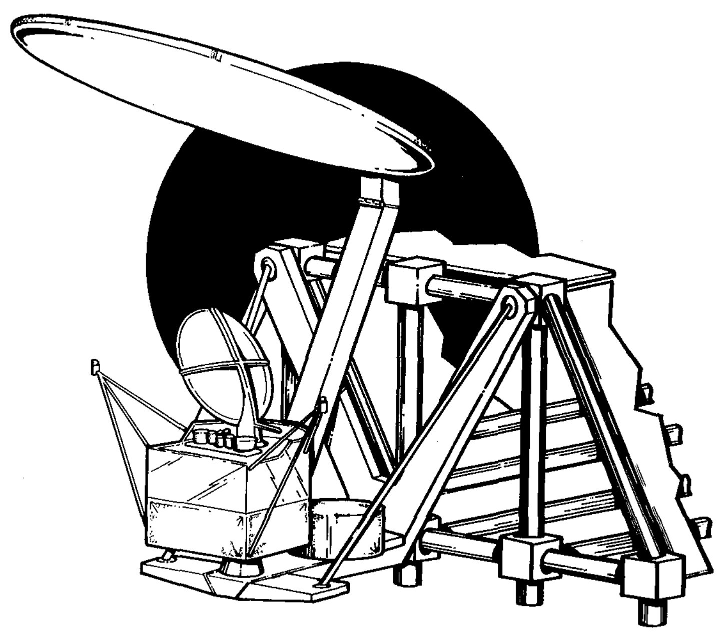
Richard Blakeslee, Marshall Space Flight Center

Steven J. Goodman, Marshall Space Flight Center

Douglas M. Mach, University of Alabama

MIMR

Multifrequency Imaging Microwave Radiometer



HIGH-RESOLUTION MICROWAVE SPECTROMETER

HERITAGE: SSM/I AND SMMR

MEASURES PRECIPITATION RATE, CLOUD WATER, WATER VAPOR, TEMPERATURE PROFILES, SEA SURFACE ROUGHNESS, SEA SURFACE TEMPERATURE, ICE, SNOW, AND SOIL MOISTURE

FREQUENCIES BETWEEN 6.6 AND 90 GHz

EXTERNAL CALIBRATION

1.6-M PARABOLIC ANTENNA AND ROTATING DRUM AT 26 RPM

MIMR is a passive microwave radiometer to be provided under a Memorandum of Understanding with the European Space Agency (ESA). MIMR will be used for retrieval of numerous atmospheric and oceanic parameters, including precipitation, soil moisture, global ice and snow cover, sea surface temperature and wind speed, atmospheric cloud water, and water vapor.

MIMR operates at six frequencies, each with horizontal and vertical polarization: 6.8, 10.65, 18.7, 23.8, 36.5, and 90 GHz. MIMR employs nine feedhorns, yielding 20 available channels. The frequencies were chosen to maximize sensitivity to particular parameters of interest and to operate in protected regions of the spectrum allocated by the CCIR. MIMR is designed to have a cross-track swath of 1,400 km at an incidence angle of 50°, which provides a 3-day global coverage of the Earth. At high latitudes (i.e., >45°), the overlap between consecutive swaths increases and daily coverage is provided.

MIMR data products will include measurements in its 20 channels covering dual polarization from 6.8 to 90 GHz with corresponding 60- to 5-km resolution, 1 to 2K accuracy, and 0.25 to 1K radiometric stability. Channels will be converted to daily spectral maps on a 1° grid; monthly average maps on 1° grids will be produced for precipitation index, sea surface temperature, snow cover parameters, sea ice parameters, atmospheric water vapor burden over oceans, atmospheric cloud water burden over oceans, ocean surface wind stress, and soil moisture index.

MIMR data can be used in conjunction with data from other EOS-A instruments. Over land, MIMR data complement visible, infrared, and active microwave observations of vegetation status, biomass, and soil moisture, which are also important for evaporation and transpiration studies. Over snow- and ice-covered areas, passive microwave data will complement high-resolution data available on surface roughness from synthetic aperture radar, thermal data, and visible multispectral measurements responsive to grain size to support extraction of moisture equivalence. Over oceans, passive microwave data, in conjunction with scatterometer and meteorological sounder data, can be used in studies of heat exchange across the air-sea surface, which are strongly dependent on measurements of sea surface temperature, wind, and atmospheric humidity in the ocean boundary layer. MIMR can also provide data on atmospheric water content and precipitation, to be interpreted in combination with AMSU-A and MHS data. ☆

FOR FURTHER INFORMATION:
European Space Agency, MIMR instrument panel report, Publication #SP-1138, Paris CEDEX 15, France.

MIMR Parameters

Measurement Approach

Passive microwave radiometer
External calibration
Retrieval of atmosphere, ocean, cryosphere, and land parameters
Multiple feedhorns (9) to cover bands from 6.8 to 90 GHz
0.25 to 1K radiometric stability
Minimum 1.6-m reflector
1-2K accuracy

Swath: 1,400 km
Spatial resolution:
- 4.86 km (90 GHz)
- 11.62 km (36.5 GHz)
- 22.3 km (23.8 GHz)
- 22.3 km (18.7 GHz)
- 38.6 km (10.65 GHz)
- 60.3 km (6.8 GHz)

Accommodation Issues

Mass: 200 kg
Duty cycle: 100%
Power: 180 W
Data rate: 62 kbps
Thermal control by: Radiator
Thermal operating range: 40°C maximum
FOV: Forward-looking conical scan
Instrument IFOV: ±80° cross-track
Pointing requirements (platform+instrument, 3σ):

Control:	TBD
Knowledge:	TBD
Stability:	TBD
Jitter:	TBD
Physical size:	1.8 x 1.7 x 1.3 m (stowed)
	3.0 x 1.7 x 1.7 m (deployed)

U.S. Team Leader—Roy W. Spencer*

Roy W. Spencer received a B.S. in Atmospheric Science from the University of Michigan, and both an M.S. and Ph.D. in Meteorology from the University of Wisconsin. Currently, Dr. Spencer is a Space Scientist at the Marshall Space Flight Center, where he directs a program of satellite passive microwave research focusing on the DMSP SSM/I, the Nimbus-7 SMMR, and the TIROS-N MSU; and the development and flight of a high-altitude aircraft five-frequency scanning microwave radiometer. Dr. Spencer has been a member of several NASA-sponsored committees, including the Tropical Rainfall Measuring Mission (TRMM) Science Steering Group, the Earth Science Geostationary Platform Committee, and the Earth System Science Subcommittee on Winds and Precipitation.

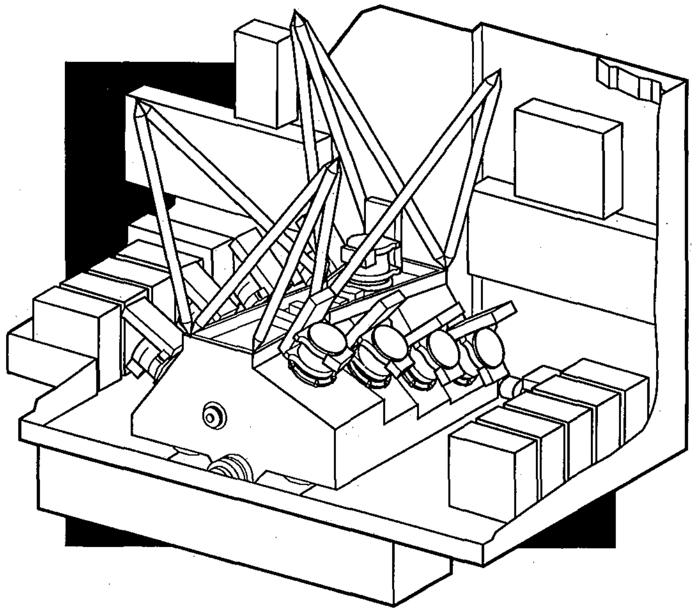
Team Members*

Although Roy Spencer has been proposed as U.S. Team Leader, his acceptance as well as other U.S. Team Members is pending negotiation with ESA. Agreement on team composition is expected by late summer 1991.

*Pending negotiation with ESA

MISR

Multi-Angle Imaging Spectro-Radiometer



HERITAGE: GLL, WIDE-FIELD/PLANETARY CAMERA

PROVIDES TOP-OF-ATMOSPHERE, CLOUD, AND SURFACE ANGULAR REFLECTANCE FUNCTIONS

PROVIDES GLOBAL MAPS OF PLANETARY AND SURFACE ALBEDO, AND AEROSOL AND VEGETATION PROPERTIES

MISR is the only EOS instrument that will routinely provide multiple-angle, continuous coverage of the Earth. The instrument will obtain multidirectional observations of each scene within the time scale of minutes, thereby under virtually the same atmospheric conditions. MISR uses nine separate charged coupled device (CCD)-based pushbroom cameras to observe the Earth at nine discrete view angles: One at nadir, plus four other symmetrical fore-aft views up to ±72.5° along-track. The views are recorded in four spectral bands, with bandcenters at 440, 550, 670, and 860 nm and bandwidths of 30, 20, 15, and 20 nm, respectively. The cameras provide continuous viewing of the sunlit side of the Earth in all bands at all angles, enabling global multi-angle imaging within the 16-day orbital repeat cycle of EOS without gaps in spatial coverage.

MISR images will be obtained in two standard spatial resolution modes. Local Mode provides 240-m pixels for selected 200 x 300 km regions. Global Mode provides 1.92-km pixels and continuous coverage of the sunlit Earth for routine, global monitoring.

Standard MISR data products will include radiometrically calibrated images in Global and Local Modes, and several other derived products as delineated below:

- Multi-angle bidirectional data for various climatically significant cloud covers with 1 percent angle-to-angle relative accuracy at the top of the atmosphere at 1.92-km spatial sampling, and multi-angle bidirectional reflectances at the surface

- Global maps of spectral planetary and surface hemispherical albedo with accuracies of ±0.03° at 1.92-km spatial sampling

- Retrieved aerosol opacities over land and ocean with accuracies of ±0.05° or 10 percent, whichever is larger, as well as other scattering properties, at 15-km resolution.

Scientific research areas that MISR data will support include study of the climatic and environmental consequences of changes in global aerosol loading; determination of how spatial and seasonal variations of different cloud types affect the planetary solar radiation budget; detection of changes in the structure, distribution, and extent of the Earth's forests, deserts, and cryosphere and investigation of the climatic implications; and study of interactions between biophysical and atmospheric processes. MISR will also provide data necessary to validate marine aerosol retrievals from MODIS and to correct HIRIS and MODIS images for atmospheric effects. Radiometric calibration of MISR will be accomplished using onboard hardware. Validation of MISR data products will result from field campaigns coordinated with other EOS investigations. ☆

MISR Parameters

Measurement Approach

Nine CCD cameras fixed at nine viewing angles out to ±72.5° forward and aft of nadir, including nadir
Four spectral bands, 440-860 nm, discriminated via filters bonded to the CCDs
Continuous global coverage in 5-16 days
0.03 hemispherical albedo accuracy
Larger of 0.05 or 10% aerosol opacity accuracy
1% angle-to-angle accuracy in bidirectional reflectance

Swath: 204 km (edited, all cameras)
357 km (unedited, nadir camera)
408 km (unedited, non-nadir cameras)
Spatial resolution: 240 m (local), 1.92 km (global)

Accommodation Issues

Mass: 102 kg
Duty cycle: 100%
Power: 47 W (average), 95 W (peak)
Data rate: 161 kbps (normal), 4.8 Mbps (peak)
Thermal control by: Radiator
Thermal operating range: -20 to +40°C

FOV: ±59° down-track by ±14° cross-track
Instrument IFOV: 204 km (edited, all cameras)
357 km (unedited, nadir camera)
408 km (unedited, non-nadir cameras)
Pointing requirements (platform+instrument, 3σ):

Control:	230 arcsec
Knowledge:	90 arcsec
Stability:	7 arcsec per 420 sec
Jitter:	1 arcsec per sec

Physical size: 127 x 68.6 x 82.5 cm

FOR FURTHER INFORMATION:

Diner, D.J., C.J. Bruegge, J.V. Martonchik, T.P. Ackerman, R. Davies, S.A.W. Gerstl, H.R. Gordon, P.J. Sellers, J. Clark, J.A. Daniels, E.D. Danielson, V.G. Duval, K.P. Klaasen, G.W. Lilienthal, D.I. Nakamoto, R.J. Pagano, and T.H. Reilly, MISR: A Multi-Angle Imaging Spectroradiometer for geophysical and climatological research from EOS, *IEEE Transactions on Geoscience and Remote Sensing*, 27, 200-214, 1989.

Principal Investigator—David J. Diner

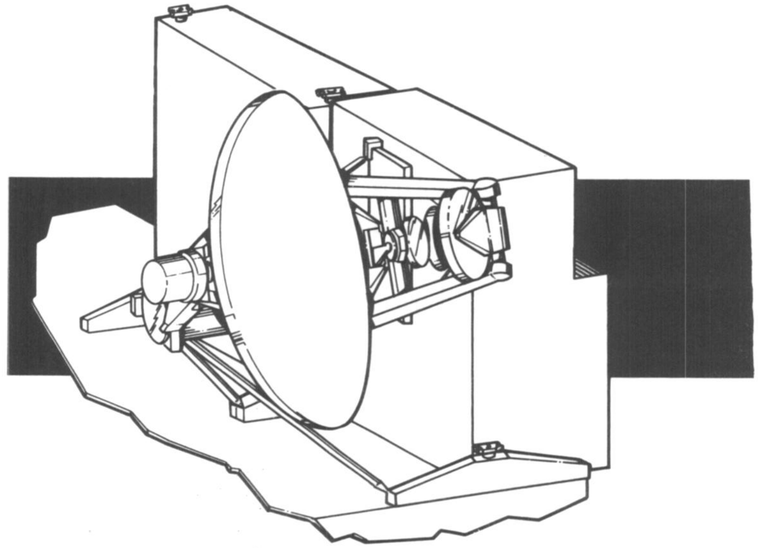
David J. Diner received a B.S. in Physics with honors from the State University of New York at Stony Brook, and an M.S. and Ph.D. in Planetary Science from the California Institute of Technology. He joined the Jet Propulsion Laboratory as a National Research Council Resident Research Associate in 1978, and is currently a Technical Group Supervisor in the Atmospheric and Cometary Sciences Section. He has been involved in numerous NASA planetary and Earth remote-sensing investigations, as Principal and Co-Investigator. He is also a member of the American Astronomical Society Division for Planetary Sciences.

Co-Investigators

Thomas P. Ackerman, Pennsylvania State University
Carol J. Bruegge, Jet Propulsion Laboratory
Roger Davies, McGill University
Siegfried Gerstl, Los Alamos National Laboratory
Howard R. Gordon, University of Miami
John V. Martonchik, Jet Propulsion Laboratory
Jan-Peter Muller, University College London
Piers Sellers, Goddard Space Flight Center

MLS

Microwave Limb Sounder



PASSIVE RADIATIONALLY COOLED MICROWAVE LIMB-SOUNDING RADIOMETER

HERITAGE: UARS MLS

MEASURES THERMAL EMISSION FROM THE ATMOSPHERIC LIMB IN SUBMILLIMETER AND MILLIMETER WAVELENGTH SPECTRAL BANDS

SPECTRAL BANDS CENTERED AT 640, 535, 440, 215, AND 63 GHz

SPECTRAL RESOLUTION: 0.01-1 MHz (0.3-3 x 10^{-5} cm^{-1})

INSTANTANEOUS FIELD-OF-VIEW AT 640 GHz: 1.2 km VERTICAL x ~300 km ALONG-TRACK x 3 km CROSS-TRACK AT THE LIMB TANGENT POINT

The MLS investigation will study and monitor atmospheric processes that govern stratospheric and mesospheric ozone. Emphasis is on chlorine and nitrogen destruction of ozone. Molecules in all ozone chemical cycles will be measured—including the radicals thought to control ozone destruction in the upper stratosphere, a sensitive region that can provide early warnings. The MLS measurements are essential for understanding stratospheric/mesospheric trends, chemistry, dynamics, climatology, and couplings with the troposphere below and thermosphere above. They will be used in several ways to gain new insights on atmospheric, climatological, and biogeochemical processes, and to constrain and test theoretical models. Measurements will be obtained continuously (82°S-82°N every orbit), even when polar stratospheric clouds are present. A vertical scan covering 0- to 120-km tangent heights in 2.5-km steps will be made each 2.5° along the orbit.

MLS data products include vertical profiles of O_3, ClO, HCl, HOCl, CH_3Cl, BrO, HO_2, H_2O_2, H_2O, NO, NO_2, N_2O, HNO_3, CO, H_2CO, HCN, SO_2, O_2, temperature, pressure, one component of mesospheric wind, and liquid water near the tropopause.

FOR FURTHER INFORMATION:

Waters, J.W., Microwave limb-sounding of Earth's upper atmosphere, *Atmospheric Research*, *23*, 391-410, 1989.

MLS Parameters

Measurement Approach
Passive limb sounder
Spectral bands centered near 63, 215, 440, 535, and 640 GHz
Thermal emission spectra collected by offset Cassegrain scanning antenna system

Limb scan: 0-120 km
Spatial resolution: 3 x 250 km horizontal x 1.4 km vertical (TBD)

Accommodation Issues
Mass: 450 kg
Duty cycle: 100%
Power: 790 W
Data rate: 1.2 Mbps
Thermal control by: Central thermal bus and locally
Thermal operating range: 10-35°C
FOV: Boresight 62-74° relative to nadir
Instrument IFOV: ±2.5° (half-cone, along-track)
Pointing requirements (platform+instrument, 3σ):
Control: 1,800 arcsec
Knowledge: 180 arcsec
Stability: 10 arcsec per 0.5 sec, 100 arcsec per 30 sec
Jitter: TBD
Physical size: 1.6 x 0.8 m (parabolic antenna)
1.2 x 2.2 x 2.0 m (first additional module)
1.2 x 0.7 x 2.0 m (second additional module)

Principal Investigator—Joe W. Waters

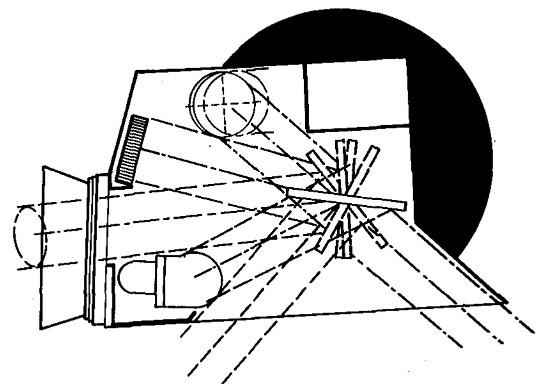
Dr. Waters has led the development of microwave limb sounding since its inception in 1974. His Ph.D. from MIT was on microwave sensing of the upper atmosphere. Afterwards he was on the MIT research staff as a Co-Investigator on Nimbus microwave experiments. He moved on to the Jet Propulsion Laboratory (JPL) in 1973, and has been Principal Investigator on aircraft, balloon, and UARS microwave limb sounding experiments. He is currently a senior research scientist at JPL, and group supervisor for the Microwave Atmospheric Science and Upper Atmosphere Experiment Development groups.

Co-Investigators

Richard E. Cofield, Jet Propulsion Laboratory
Lucien Froidevaux, Jet Propulsion Laboratory
Robert S. Harwood, University of Edinburgh
Robert F. Jarnot, Jet Propulsion Laboratory
Brian J. Kerridge, Rutherford Appleton Laboratory
David N. Matheson, Rutherford Appleton Laboratory
Gordon E. Peckham, Heriot-Watt University
William G. Read, Jet Propulsion Laboratory
Peter H. Siegel, Jet Propulsion Laboratory
William J. Wilson, Jet Propulsion Laboratory

MODIS-N/T

Moderate-Resolution Imaging Spectrometer-Nadir/Tilt



Moderate-Resolution Imaging Spectrometer-Nadir

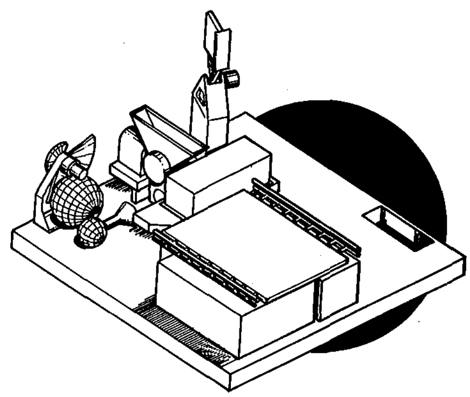
MODIS-T IS AN IMAGING SPECTROMETER WITH IN-TRACK TILT CAPABILITY

MODIS-N IS AN IMAGING SPECTROMETER WITH NO TILT CAPABILITY

HERITAGE: AVHRR, HIRS, LANDSAT TM, AND NIMBUS-7 CZCS

BOTH MEASURE BIOLOGICAL AND PHYSICAL PROCESSES

MODIS-N ALSO A CANDIDATE FOR THE EOS-B SERIES



Moderate-Resolution Imaging Spectrometer-Tilt

MODIS-N is an EOS-A facility instrument designed to measure biological and physical processes that do not require along-track pointing. The instrument employs a conventional imaging radiometer concept, consisting of a cross-track scan mirror and collecting optics, and a set of individual detector elements. The optical arrangement will provide imagery in 36 discrete bands between 0.4 and 14.54 μm selected for diagnostic significance in Earth science. The spectral bands will have spatial resolution of 250 m, 500 m, or 1 km at nadir; signal-to-noise ratio of greater than 500 at 1-km resolution (at a solar zenith angle of 70°); and absolute irradiance accuracy of ±5 percent from 0.4 to 3 μm (2% relative to the sun) and 1 percent in the thermal infrared (3 to 15 μm). MODIS-N will provide daylight reflection and day/night emission spectral imaging of any point on the Earth at least every 2 days, with continuous duty cycle.

The instrument has a general objective of providing long-term observations to improve understanding of global dynamics and processes occurring on the surface of the Earth and in the lower atmosphere. MODIS-N will provide specific global survey data products, which include the following:

- Surface temperature with 1-km resolution, day and night, with absolute accuracy of 0.2K for oceans and 1K for land
- Ocean color, defined as ocean-leaving spectral radiance within 5 percent from 415 to 653 nm, based on adequate atmospheric correction from infrared sensor channels
- Chlorophyll fluorescence within 50 percent at surface water concentrations of 0.5 mg/m^{-3} of chlorophyll *a*
- Concentration of chlorophyll *a* within 35 percent
- Vegetation/land surface cover, conditions, and productivity, defined as

- Net primary productivity, leaf area index, and intercepted photosynthetically active radiation
- Land cover type with change detection and identification
- Vegetation indices corrected for atmosphere, soil, polarization, and directional effects
- Snow cover and snow reflectance

• Cloud cover with 500-m resolution by day and 1,000-m resolution at night

• Cloud properties characterized by cloud droplet phase, optical thickness, droplet size, cloud-top pressure, and emissivity

• Aerosol properties defined as optical thickness, particle size, and mass transport

• Fire occurrence, size, and temperature

• Global distribution of atmospheric stability and total precipitable water. ☆

MODIS-T is a grating-type imaging spectrometer for the measurement of biological and physical processes, with emphasis on the study of ocean primary productivity and biogeochemistry. Reflected sunlight enters the MODIS-T optics and reflects off a diffraction grating. The spectrally dispersed light is projected onto a detector array, which allows measurement of discrete wavelength intervals (approximately 15 nm) over moderate spatial resolutions (1.1 km at nadir). During the course of each scan, 32 spectral intervals from 400 to 880 nm are observed with a signal-to-noise ratio (SNR) of greater than 500 in each band for solar zenith angles up to 70°.

During each scan, MODIS-T covers a 1,500-km across-track and 33-km along-track swath centered at nadir. It has the capability of ±45° cross-track and +67.5° (fore)/-50° (aft) along-track tilting for sun-glint avoidance, for the examination of the bidirectional reflectance distribution function of large homogeneous targets, and for viewing the moon for calibration purposes. Because the reflectance of the ocean is much less than that from clear land or clouds, the MODIS-T instrument is designed to dynamically select an appropriate gain so that a high SNR is maintained.

In oceans and lakes, MODIS-T data will be used to retrieve global measurements of surface water chlorophyll concentration, primary productivity, dissolved organic matter, and sediment transport. Through global observations of ocean color, MODIS-T data products will permit improved estimates of phytoplankton biomass and oceanic photosynthetic potential, leading to improved understanding of the transformation of inorganic carbon into organic forms as part of the global carbon cycle. Ocean color observations, along with sea surface temperature measurements from MODIS-T and other sources, will contribute to the determination of ocean flow dynamics.

On land, MODIS-T will provide measurements of standing water, wetland extent, vegetation properties, bidirectional reflectance, and hemispherical albedo. Cloud and aerosol properties will also be derived from MODIS-T data. ☆

FOR FURTHER INFORMATION:

Salomonson, V.V., W.L. Barnes, P.W. Maymon, H.E. Montgomery, and H. Ostrow, MODIS: Advanced facility instrument for studies of the Earth as a system, *IEEE Transactions on Geoscience and Remote Sensing*, 27, 3, 145-153, 1989.

MODIS-N Parameters

Measurement Approach

36 observing bands
Polarization sensitivity is less than 2%
SNR greater than 500 at 1-km resolution
Absolute irradiance accuracy of 5% at the instrument
Absolute temperature accuracy 0.2K for oceans and 1K for land
Daylight reflection and day/night emission spectral imaging
Swath: 2,300 km
Spatial resolution (IFOVs): 250 m (cloudcover), 500 m, 1,000 m (surface temperature)

Accommodation Issues

Mass: 200 kg
Duty cycle: 100%
Power: 225 W (average), 275 W (peak)

Data rate: 5.5 Mbps (average), 11 Mbps (day), 1.7 Mbps (night)
Thermal control by: Radiator
Thermal operating range: TBD
FOV: ±55° cross-track
Instrument IFOV: 250 m (cloud cover), 500 m, 1,000 m (surface temperature)

Pointing requirements (platform+instrument, 3σ):

Control:	3,600 arcsec
Knowledge:	105 arcsec
Stability:	15.6 μrad
Jitter:	TBD
Physical size:	1 x 1 x 1.6 m (stowed, covers and shields to be deployed)

MODIS-T Parameters

Measurement Approach

Whiskbroom scan: Scan mirror provides cross-track inputs over ±45° (1,500 km); scan mirror tilt provides fore/aft tilt up to +67.5° and -50°
Grating-type reflecting Schmidt imaging spectrometer
30 x 34 pixel photodioxide/charged coupled device interline detector
Absolute irradiance measurement accuracy to 5%
Angular resolution and accuracy of 1.56 mrad

Swath: 1,500 km at nadir
Spatial resolution: 1.1 x 1.1 km at nadir

Accommodation Issues

Mass: 170 kg
Duty cycle: 100% (daylight only)
Power: 130 W (average), 155 W (peak)
Data rate: 3.076 Mbps (day), 0.118 Mbps (night)
Thermal control by: Thermal electric cooler, heaters, central thermal bus, radiator
Thermal operating range: 20°C (sensor), 0-40°C (electronics)
FOV: ±45° cross-track, +67.5° (fore)/-50° (aft) along-track
Instrument IFOV: 1.56 mrad
Pointing requirements (platform+instrument, 3σ):

Control:	1°
Knowledge:	141 arcsec
Stability:	TBD
Jitter:	TBD
Physical size:	140 x 125 x 56 cm (stowed) 140 x 125 x 87 cm (deployed)

Team Leader

Vincent Salomonson has over 25 years of experience in the fields of meteorology, agricultural engineering, atmospheric science, and hydrology. He was awarded a Ph.D. in Atmospheric Science from Colorado State University in 1968, the year he joined Goddard Space Flight Center (GSFC). He was recently appointed Director of Earth Sciences at GSFC.

Dr. Salomonson brings substantial experience to his role as Team Leader of MODIS. He has functioned informally and formally as the MODIS Team Leader for the past 5 years. He also has over a dozen years of experience as the Landsat 4 and 5 Project Scientist, including the leadership and management of the Landsat Image Data Quality and Analysis (LIDQA) Investigator Team and Thematic Mapper research in the Earth Sciences Investigator Team. Additional experience includes over 16 years as a line manager of research groups at GSFC and the leadership of the NASA Water Resources Subdiscipline Panel and Program for several years in the 1970s. He has published research materials directly relevant to the investigation, and has over 100 refereed publications, conference proceedings, and NASA reports to his credit.

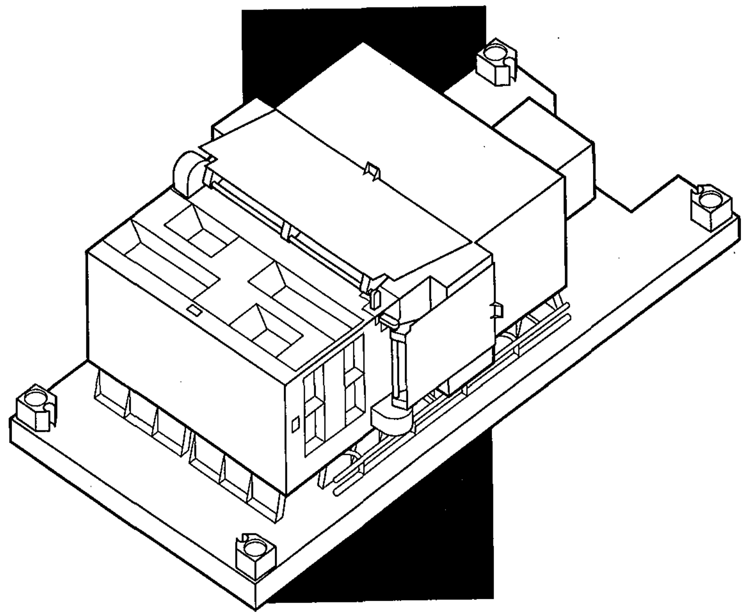
Cited on numerous occasions for his outstanding research and scientific achievement, Dr. Salomonson is the recipient of eight NASA awards for exceptional achievement, service, and performance; the Distinguished Achievement Award of the IEEE Geoscience and Remote Sensing Society; the William T. Pecora Award; and the Distinguished Alumnus Award from Colorado State University. In addition to his present duties at Goddard, he also serves as the President of the American Society for Photogrammetry and Remote Sensing.

Team Members

Mark R. Abbott, Oregon State University
William Barnes, Goddard Space Flight Center
Ian Barton, CSIRO
Otis B. Brown, University of Miami
Kendall L. Carder, University of South Florida
Dennis K. Clark, NOAA/NESDIS
Wayne Esaias, Goddard Space Flight Center
Robert H. Evans, University of Miami
Howard R. Gordon, University of Miami
Frank E. Hoge, Wallops Flight Center
Alfredo R. Huete, University of Arizona
Christopher O. Justice, Goddard Space Flight Center
Yoram J. Kaufman, Goddard Space Flight Center
Michael D. King, Goddard Space Flight Center
Paul Menzel, NOAA/NESDIS
Jan-Peter Muller, University College London
John Parslow, CSIRO
Steven W. Running, University of Montana
Philip N. Slater, University of Arizona
Alan H. Strahler, Boston University
Didier Tanre, Univ. des Sciences et Techniques de Lille
Vern Vanderbilt, Ames Research Center
Zhengming Wan, University of California, Santa Barbara

MOPITT

MEASUREMENTS OF POLLUTION IN THE TROPOSPHERE



FOUR-CHANNEL CORRELATION SPECTROMETER WITH CROSS-TRACK SCANNING

HERITAGE: PRESSURE-MODULATED CELL ELEMENTS USED IN THE PMR, SAMS, AND ISAMS INSTRUMENTS, USING SIMILAR CORRELATION SPECTROSCOPY TECHNIQUES

MEASURES UPWELLING RADIANCE AT 2.3, 2.4, AND 4.7 μM

USES PRESSURE MODULATION AND LENGTH MODULATION CELLS TO OBTAIN CO CONCENTRATIONS IN 3-KM LAYERS AND CH_4 COLUMN

The MOPITT experiment is provided under a Memorandum of Understanding with the Canadian Space Agency (CSA). MOPITT measures emitted and reflected infrared radiance in the atmospheric column. Analysis of these data permit retrieval of tropospheric CO profiles and total column CH_4. MOPITT will measure tropospheric CO and CH_4 concentrations to study how these gases interact with the surface, ocean, and biomass systems. The information provided below was accurate at the time of publication, but is subject to change pending results of a 90-day study initiated in February 1991, to finalize the instrument specifications.

MOPITT operates on the principle of correlation spectroscopy (i.e., spectral selection of radiation emission or absorption by a gas using a sample of the same gas as a filter). The instrument modulates sample gas density by changing the length or the pressure of the gas sample in the optical path of the instrument. This modulation changes the absorption profile in the spectral lines of the gas in the cell as observed by a detector. Thus, the AC output of the detector, measured at the frequency that the gas sample is modulated, will be equal to the radiation detected, if the gas cell and its modulator were replaced by an optical filter with a profile that matches the absorption features of the sample gas in the modulator cell.

Atmospheric profiles of CO are derived using thermal radiation at 4.7 μm. Column CO and CH_4 are measured using channels at 2.4 and 2.3 μm, respectively, to sense solar radiation reflected from the surface. The solar channels are duplicated in the instrument at different correlation cell pressures, to allow a failure in one channel without compromising the column measurement.

MOPITT is designed as a scanning instrument. It has a field-of-view of 1.8°, which is equivalent to an approximately 22-km footprint at nadir. The instrument scan line consists of 28 pixels, each at 1.8° increments. Thus, the maximum scan angle is 25.2° off-axis, which is equivalent to a swath width of 620 km. This swath leaves gaps in coverage between successive orbits using the nominal 705-km altitude and 98.2° inclination orbit.

MOPITT data products will include gridded retrievals of CH_4 with a horizontal resolution of 120 km and a precision of 1 percent. Gridded CO soundings will be retrieved with 10 percent accuracy in three vertical layers between 0 and 15 km. These soundings will be taken at laterally scanned sampled locations with 22-km horizontal resolution. Column CO abundance will be retrieved and gridded with 66-km horizontal resolution. Scientific studies will employ these data to derive 3-D global maps as part of an effort to model global tropospheric chemistry. ☆

FOR FURTHER INFORMATION:
Drummond., J.R., Measurements of Pollution in the Troposphere (MOPITT), in *The Use of EOS to Study Atmospheric Physics*, J. Gille and G. Visconti (ed.), North Holland, 1991.

MOPITT Parameters

Measurement Approach

Correlation spectroscopy utilizing both pressure-modulated and length-modulated gas cells, with detectors at 2.3, 2.4, and 4.7 µm
Vertical profile of CO and total column of CH_4 to be measured
CO concentration accuracy is 10%
CH_4 column abundance accuracy is 1%

Swath: 616 km
Spatial resolution: 22 x 22 km

Accommodation Issues

Mass: 87 kg
Power: 200 W
Duty cycle: 100%
Data rate: 3.1 kbps (average), 4.5 kbps (peak, calibration only)
Thermal control by: 80K Stirling cycle cooler, central thermal bus
Thermal operating range: 25°C (instrument), 100K (detectors)
FOV: 22 x 616 km (scanned, 28 fields)
Instrument IFOV: 22 x 22 km (1.8 x 1.8°)
Pointing requirements (platform+instrument, 3σ):
Control: TBD
Knowledge: TBD
Stability: TBD
Jitter: TBD
Physical size: 0.915 x 0.767 x 0.486 m (stowed)
0.915 x 0.767 x 0.525 m (deployed)

Principal Investigator—James Drummond

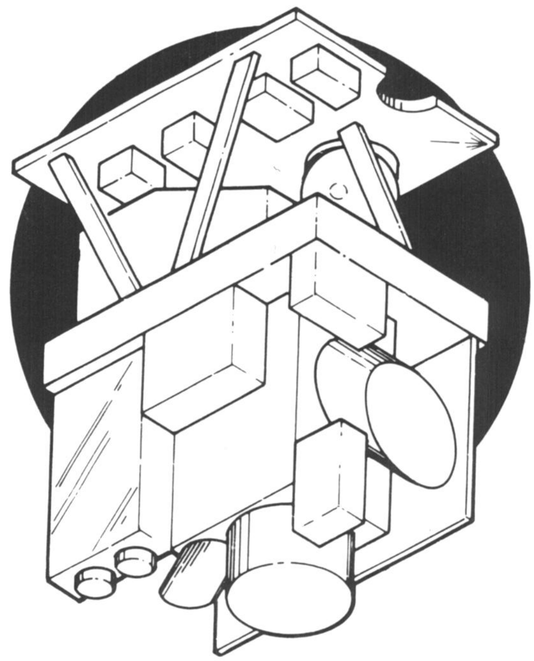
James Drummond has taught in the Physics Department of the University of Toronto since 1979, as Associate Professor since 1984. He studied at Oxford University where he obtained his B.A. and D.Phil. degrees in Physics. He was a Visiting Scientist in the Atmospheric Chemistry Division of the National Center for Atmospheric Research in 1987. His research interests are in the field of atmospheric measurements and modeling, and he has participated in several balloon and spacecraft experiments in said areas. Dr. Drummond has presented research papers at international meetings and symposia, and in refereed journals.

Co-Investigators (Additional Members to be Selected)

Guy Brasseur, National Center for Atmospheric Research
John C. Gille, National Center for Atmospheric Research
J. McConnell, York University
Guy D. Peskett, Oxford University

SAFIRE

SPECTROSCOPY OF THE ATMOSPHERE USING FAR INFRARED EMISSION



SEVEN-CHANNEL FAR-INFRARED FOURIER TRANSFORM SPECTROMETER (0.004 cm^{-1} SPECTRAL RESOLUTION) AND SEVEN-CHANNEL MID-INFRARED BROADBAND LIMS-TYPE RADIOMETER

HERITAGE: LRIR, LIMS, SAMS, ATMOS

GLOBALLY MEASURES CHEMICAL, RADIATIVE, AND DYNAMICAL PROCESSES THAT INFLUENCE OZONE CHANGES

COVERS SPECTRAL RANGES 80-160, 310-390, AND 630-1,560 cm^{-1}

SENSOR MODULES OPTICALLY COUPLED THROUGH COMMON TELESCOPE

FORE AND AFT VIEWING PROVIDES NEARLY COMPLETE GLOBAL COVERAGE (86°N TO 86°S)

The goal of the SAFIRE experiment is to improve understanding of the middle atmosphere ozone distribution by conducting global-scale measurements of the chemical, radiative, and dynamical processes that influence ozone changes. SAFIRE is a passive limb emission instrument that combines the advantages of far-infrared Fourier transform spectroscopy and space-proven mid-infrared broadband radiometry. The experiment provides simultaneous observations of key Oy, HOy, NOy, ClOy, and BrOy gases, coupled with dynamical tracer measurements, including vertical profiles of temperature, O_3, O_3^{50}, $O(^3P)$, OH, HO_2, H_2O_2, H_2O, HDO, CH_4, NO_2, HNO_3, N_2O, N_2O_5, HCl, HOCl, HBr, and HF. This list includes 10 of 13 gases considered to be critical for observing long-term middle atmosphere changes; temperature, O_3, and related gases needed to provide the earliest detection and study of stratospheric changes due to increases in greenhouse and halogen gases; measurements of the main halogens (i.e., HCl, HF, and HBr) needed to study long-term increases in chlorine and bromine, and to assess anthropogenic perturbations to the atmosphere; and stratospheric H_2O, HDO, and CH_4 measurements needed to study possible changes in H_2O input to the stratosphere due to any long-term changes in climate-related responses of tropopause temperature and stratospheric circulation. Other important applications include heterogeneous chemistry studies enabled by the ability to both detect thick PSCs and volcanic aerosols, and to measure temperature and key constituents even in their presence; studies of polar night chemistry, diurnal change, dynamics and transport processes, chemistry, and dynamics coupling; and analyses of lower stratospheric phenomena. ☆

FOR FURTHER INFORMATION:

Russell III, J.M., An overview of the Spectroscopy of the Atmosphere using Far Infrared Emission (SAFIRE) experiment, *Proceedings of the International SPIE meeting*, April 1991.

SAFIRE Parameters

Measurement Approach

Swath: Limb viewing from 0-106 km to within 4° of the poles
Spatial resolution: 3 km vertical (far-infrared), 1.5 km vertical (mid-infrared)

Accommodation Issues

Mass: 407 kg
Duty cycle: 100%
Power: 465 W
Data rate: 8.7 Mbps

Thermal control by: Five 80K Stirling cycle coolers (4 single-stage, 1 double-stage for mid-infrared sensors), heater, radiator, 4K cryogens (for far-infrared sensor)
Thermal operating range: -10 to +30°C
FOV: 1 x 1° square swept over a depression angle of 17 to 29° (10° from the orbital plane)
Pointing requirements (platform+instrument, 3σ):

Control:	750 arcsec
Knowledge:	10 arcsec
Stability:	1 arcsec per 9 sec
Jitter:	TBD
Physical size:	1.6 x 1.6 x 1.6 m

Principal Investigator—James M. Russell III

Dr. Russell received a Ph.D. in Aeronomy from the University of Michigan. He presently serves as Head of the Theoretical Studies Branch, Atmospheric Sciences Division, at the Langley Research Center. Since 1970, he has concentrated on atmospheric science and remote sensing research. He served as Co-Team Leader of LIMS, launched on Nimbus-7 in 1978; Co-Investigator on the Spacelab 3 ATMOS experiment, launched on the Shuttle in 1985; and is Principal Investigator on HALOE and a Co-Investigator on ISAMS, both of which are scheduled to fly on UARS in 1991. He has been a Visiting Scientist at NCAR, is listed in several biographical periodicals that recognize achievement in science, has received the NASA Medal for Exceptional Scientific Achievement, and holds two U.S. patents.

Co-Investigators

John Ballard, Rutherford Appleton Laboratory
Bruno Carli, Consiglio Nazionale Delle Ricerche
Frank DeLucia, Ohio State University
Paul H.G. Dickinson, Rutherford Appleton Laboratory
Larry L. Gordley, G&A Technical Software, Inc.
William L. Grose, Langley Research Center
John E. Harries, Rutherford Appleton Laboratory
Ira G. Nolt, Langley Research Center
Jae H. Park, Langley Research Center
John A. Pyle, Cambridge University
Ellis E. Remsberg, Langley Research Center
Clive D. Rodgers, Oxford University
Susan Solomon, NOAA/Environmental Research Laboratory
Adrian F. Tuck, NOAA/Environmental Research Laboratory

SAGE III

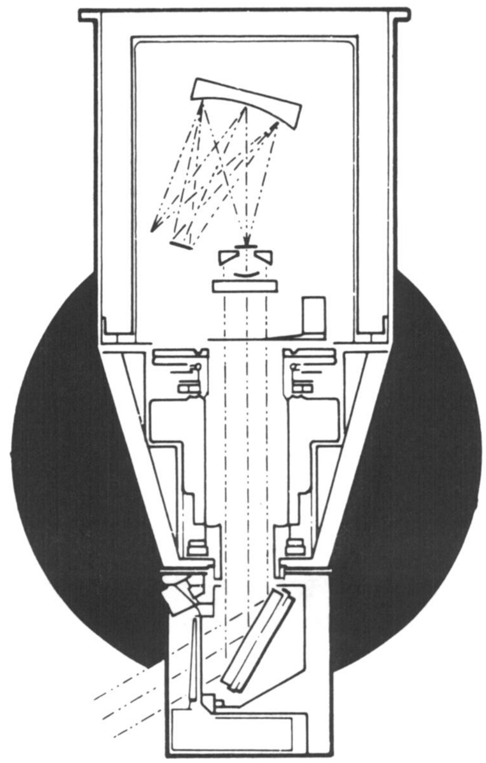
Stratospheric Aerosol and Gas Experiment III

EARTH LIMB-SCANNING GRATING SPECTROMETER

HERITAGE: SAM II, SAGE I, AND SAGE II

OBTAINS GLOBAL PROFILES OF AEROSOLS, O_3, H_2O, NO_2, NO_3, OCLO, CLOUDS, TEMPERATURE, AND PRESSURE IN THE MESOSPHERE, STRATOSPHERE, AND TROPOSPHERE

1- TO 2-KM VERTICAL RESOLUTION



SAGE III will measure profiles of aerosols, O_3, NO_2, NO_3, OClO, H_2O, temperature, and pressure between cloud tops and the upper mesosphere with 1- to 2-km vertical resolutions. The instrument is a natural and improved extension of the successful Stratospheric Aerosol Measurement II (SAM II), SAGE I, and SAGE II experiments, and will include additional wavelengths and lunar occultation to accomplish the following:

- Improve aerosol characterization
- Improve the gaseous retrievals of O_3, H_2O, NO_2, NO_3, and OClO
- Extend the vertical range of measurement
- Provide total self-calibration independence from any external data needed for retrieval.

SAGE III will be capable of making long-term trend measurements, and will provide aerosol and cloud data important to radiative and atmospheric chemistry studies. The instrument also provides data essential for the calibration and interpretation of data from other remote sensors. ☆

FOR FURTHER INFORMATION:

McCormick, M.P., SAGE III capabilities and global change, in *29th Aerospace Sciences Meeting,* American Institute of Aeronautics and Astronautics, Washington, D.C., 1991.

SAGE III Parameters

Measurement Approach

Self-calibrating solar and lunar occultation, with nine spectral channels, from 290 to 1,550 nm, to study aerosols, ozone, OClO, NO_2, NO_3, water vapor, temperature, and pressure

Swath: n/a (looks at sun through Earth's limb)
Spatial resolution: 1-2 km vertical

Accommodation Issues

Mass: 35 kg
Duty cycle: During solar and lunar Earth occultation
Power: 8 W (average), 40 W (peak)

Data rate: 87 kbps for 8 min, twice per orbit
Thermal control by: Radiators
Thermal operating range: 10-30°C
FOV: ±180° azimuth, 19 to 29° elevation
Instrument IFOV: <0.5 km vertical at 20-km tangent height
Pointing requirements (platform+instrument, 3σ):

Control:	300 arcsec
Knowledge:	2°
Stability:	30 arcsec per sec
Jitter:	TBD
Physical size:	25 x 25 x 42 cm
	29.2-cm diameter x 80.5 cm

Principal Investigator—M. Patrick McCormick

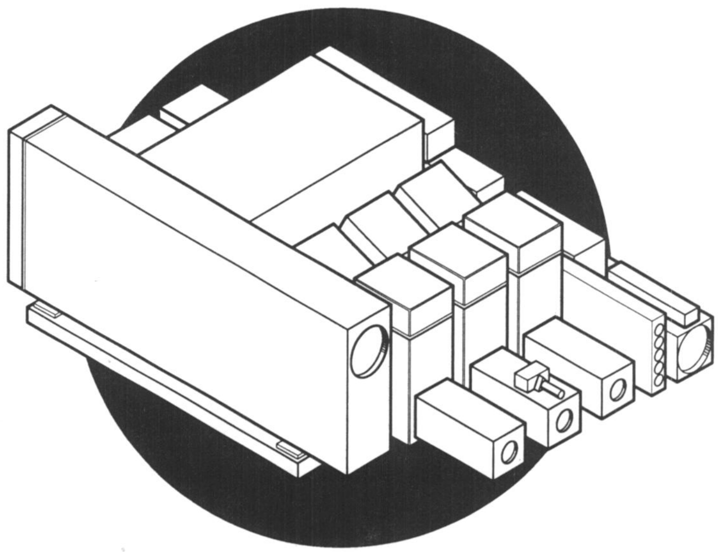
M. Patrick McCormick received an M.A. and Ph.D. in Physics from the College of William & Mary. He has been with NASA/Langley Research Center since 1967, and is presently Head of the Aerosol Research Branch. Dr. McCormick is Principal Investigator on SAM II, SAGE I, SAGE II, and LITE spaceflight experiments, as well as numerous other atmospheric remote sensing instrument and data analysis experiments. He received the Arthur S. Flemming Award for Outstanding Young People in Federal Service in 1979, the NASA Exceptional Scientific Achievement Medal in 1981, the American Meteorological Society's Jule G. Charney Award in 1991, and numerous NASA Group or Special Achievement Awards. In addition, he received an Honorary Doctor of Science degree from the Washington & Jefferson College in 1981, where he presently serves on the Board of Trustees. Dr. McCormick is a member of the International Radiation Commission, the American Meteorological Society, and the American Geophysical Union, and chairs the International Coordination Group on Laser Atmospheric Studies.

Co-Investigators

Barry Bodhaine, NOAA/Environmental Research Laboratory
William P. Chu, Langley Research Center
D.M. Cunnold, Georgia Institute of Technology
John DeLuisi, NOAA/Environmental Research Laboratory
Philip A. Durkee, Naval Postgraduate School
Benjamin M. Herman, University of Arizona
Peter V. Hobbs, University of Washington
Geoffrey Kent, Science & Technology Corporation
Jacqueline Lenoble, Universite des Sciences et Techniques de Lille
Alvin J. Miller, NOAA/National Meteorological Center
Volker Mohnen, New York State University
Venkatachalam Ramaswamy, Princeton University
David H. Rind, Goddard Institute for Space Studies
Philip B. Russell, Ames Research Center
Vinod K. Saxena, North Carolina State University
Eric Shettle, Air Force Geophysics Laboratory
Gabor Vali, University of Wyoming
Steven Wofsy, Harvard University
Joseph M. Zawodny, Langley Research Center

SOLSTICE II

Solar Stellar Irradiance Comparison Experiment II



FOUR-CHANNEL ULTRAVIOLET (UV) SPECTROMETER (TWO-AXIS SOLAR TRACK)

COMPOSED OF AN ULTRA HIGH-RESOLUTION SPECTROMETER, LOW-RESOLUTION SPECTROMETERS, AND AN XUV PHOTOMETER

HERITAGE: UARS SOLSTICE

RANGE OF 115 TO 440 NM

THREE CHANNELS HAVE A SPECTRAL RESOLUTION OF 0.2 NM; THE FOURTH CHANNEL HAS A RESOLUTION OF 0.0015 NM

PROVIDES DAILY MEASUREMENT OF FULL-DISK SOLAR UV IRRADIANCE, WITH CALIBRATION MAINTAINED BY COMPARISON TO BRIGHT, EARLY-TYPE STARS (1% ACCURACY)

SOLSTICE II provides precise daily measurements of the full-disk solar ultraviolet irradiance between 5 and 440 nm. The sun's ultraviolet radiation is the dominant energy source to the Earth's atmosphere, and small changes in the radiation field have an important impact on atmospheric temperature, chemistry, structure, and dynamics. Moreover, even small alterations in the atmosphere (e.g., small changes in total ozone) can produce dramatic differences in the solar radiation reaching the Earth's surface.

The SOLSTICE II instrument consists of a four-channel spectrometer together with the required gimbal system to point the instrument at the sun and selected stars. The stellar targets, observed with the same optics and detectors as those directed at the sun, are essential for they determine the long-term drift correction to the SOLSTICE II calibration. The ensemble average flux from these 30 or so bright early-type stars should remain absolutely constant over arbitrarily long time periods. This unique method thereby establishes the instrument response as a function of time throughout the EOS mission, and yields time series of solar variability that are completely corrected for instrumental drift.

The SOLSTICE II investigation will also model the penetration of solar radiation down into the Earth's atmosphere and establish the radiation field at all locations and altitudes, including the Earth's surface. In certain wavelength intervals, the depth of penetration varies dramatically due to details in the atmospheric absorption, and calculations require solar data with very high spectral resolution. To accommodate these measurements, a separate, high-resolution spectrometer channel—SURE—is included in the SOLSTICE II. ☆

FOR FURTHER INFORMATION:

Rottman, G.J. and T.N. Woods, In-flight calibration of solar irradiance measurements by direct comparison with stellar observations, in *Recent Advances in Sensors, Radiometry, and Data Processing for Remote Sensing,* 136-143, Society of Photo-Optical Instrumentation Engineers, Bellingham, WA, 1988.

SOLSTICE II Parameters

Measurement Approach
Spectral range from 5 to 440 nm
Photometric accuracy better than 5% absolute (1% relative)
Spectral resolution: 0.2 and 0.0015 nm

Swath: n/a
Spatial resolution: n/a

Accommodation Issues
Mass: 90.5 kg
Duty cycle: 74% data taking
Power: 34 W (99% of time), 42 W (1% of time)

Data rate: 5 kbps (average), 8 kbps (peak)
Thermal control by: Radiator
Thermal operating range: 0-30°C (15° average)
FOV: 1.5°
Instrument IFOV: n/a
Pointing requirements (celestial pointer, 3σ):

Control:	±6 arcmin
Knowledge:	60 arcsec
Stability:	60 arcsec per 15 min
Jitter:	15 arcsec per sec
Physical size:	102 x 69 x 33 cm

Principal Investigator—Gary Rottman

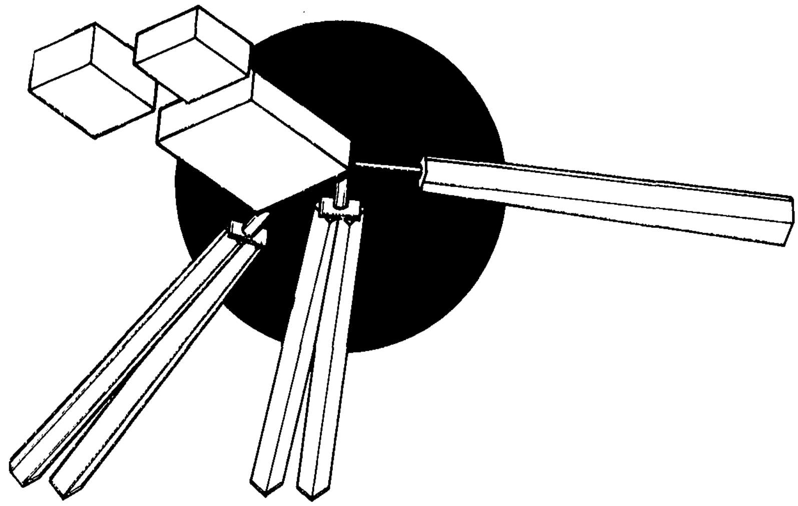
Gary Rottman, who holds an M.S. and Ph.D. in Physics from The Johns Hopkins University, has concentrated his professional career at the University of Colorado. He is presently Senior Research Associate in that institution's Laboratory for Atmospheric and Space Physics. His space research includes roles as Principal or Co-Investigator on numerous solar and atmospheric investigations, including Solar-Mesosphere Explorer, SOLSTICE/UARS Program, and Solar EUV SPARTAN and Rocket Programs.

Co-Investigators

Elaine R. Hansen, University of Colorado
George M. Lawrence, University of Colorado
Julius London, University of Colorado
Raymond G. Roble, National Center for Atmospheric Research
Paul C. Simon, Belgian Institute of Space Aeronomy
Tom N. Woods, University of Colorado

STIKSCAT

STICK SCATTEROMETER



SIX STICK, FAN-BEAM KU BAND SCATTEROMETER

HERITAGE: SEASAT, NSCAT

ONBOARD DIGITAL DOPPLER FILTERING FOR ALONG-BEAM RESOLUTION

ACQUIRES ALL-WEATHER MEASUREMENTS OF SURFACE WIND SPEED AND DIRECTION OVER THE GLOBAL OCEANS

STIKSCAT is designed to acquire accurate, high-resolution, continuous, all-weather measurements of near-surface vector winds over the ice-free global oceans. As the only instrument capable of acquiring measurements of wind velocity—both speed and direction—under all-weather conditions, STIKSCAT data are crucial for studies of tropospheric dynamics and air-sea momentum fluxes.

STIKSCAT transmits pulses of microwave radiation at 14 GHz and measures the backscattered signal from the ocean. With knowledge of the range and instrument parameters such as antenna gain, the backscattered power data can be used to calculate directly the normalized radar cross section (σ_0) of the sea surface.

At moderate incidence angles, the received power is primarily a result of Bragg scattering from centimetric ocean waves whose amplitudes and directional distributions are in approximate equilibrium with the local wind. Thus, the backscattered power (hence σ_0) will vary as a function of wind speed and wind direction relative to the radar beam. An empirically based geophysical model function relates σ_0 to wind speed and relative direction as a function of incidence angle, polarization, and frequency of the incident and backscattered radiation; multiple measurements of σ_0 from the same area on the sea surface, but having different directions relative to the wind, are used to invert the model function to derive both wind speed and wind direction simultaneously.

STIKSCAT uses a total of six fan-beam antennae, three on each side, to acquire measurements in two continuous, 600-km-wide swaths, separated by a 325-km gap at nadir. All six antenna transmit and receive vertically polarized radiation; one antenna on each side also transmits/receives horizontal polarization. The multiple antennae are aligned at different azimuth angles to acquire the multi-directional data needed to invert the model function. Owing to spacecraft orbital velocity and Earth rotation, the backscattered power is Doppler-shifted as a function of spatial location. For STIKSCAT, along-beam resolution is achieved using an onboard digital processor that Fourier transforms the received signal, resulting in 25-km resolution measurement cells.

Data products from STIKSCAT will consist of global multi-azimuth σ_0 measurements; 25-km resolution ocean vector winds (~12% speed and 16-18° direction accuracies from 3-50 m/sec) in each of the swaths; and spatially and temporally averaged wind field maps with 1° spatial resolution and 2-day temporal resolution. STIKSCAT measures vector winds over ~79% of the global oceans each day, with virtually complete coverage in every 2-day period. The wind velocity data from STIKSCAT will be used for calculating all air-sea fluxes, for modeling upper ocean circulation and tropospheric dynamics, and for improving global weather predictions. ✩

FOR FURTHER INFORMATION:
Naderi, F.M., M.H. Freilich, and D.G. Long, Spaceborne radar measurement of wind velocity over the ocean: An overview of the NSCAT scatterometer system, *Proceedings of the Institute for Electronics and Electrical Engineers*, June 1991 (in press).

STIKSCAT Parameters

Measurement Approach
Active microwave radar at 14 GHz
Six fan-beam antennae used to determine radar scattering cross section and infer surface wind velocity over the ocean
All-weather capability
Wind speeds between 3-50 $msec^{-1}$ accurate to 12%
Wind vector directions accurate to 16-18°

Swath: Two 600-km swaths separated by 325-km gap at nadir
Spatial resolution: 25 x 25 km

Accommodation Issues
Mass: 297 kg, plus 100 kg of accommodation hardware
Power: 290 W
Duty cycle: 100%
Data rate: 5.2 kbps
Thermal control by: Central thermal bus
Thermal operating range: 5-50°C
FOV: Complex fan beam from antennae resulting in two 600-km-wide swaths separated by a 325-km gap at nadir
Instrument IFOV: ±50° from each antenna
Pointing requirements (platform+instrument, 3σ):

Control:	324 arcsec
Knowledge:	216 arcsec
Stability:	396 arcsec per 1,800 sec
Jitter:	TBD
Physical size:	318 x 20 x 18 cm (antennae)
	122 x 91 x 25 cm (RFS/REU)
	84 x 48 x 25 cm (DSS)
	38 x 48 x 25 cm (RES/DIU)

Requires spatially and temporally co-located multi-channel microwave radiometer measurements for rain correction.

Principal Investigator—Michael Freilich

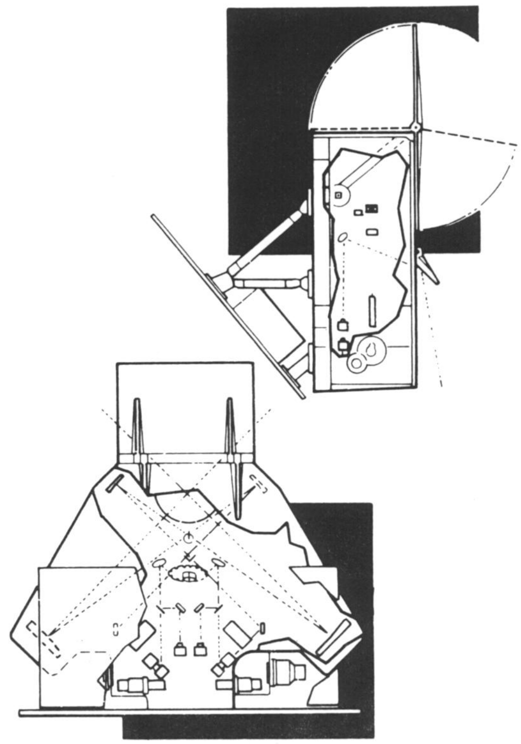
Michael Freilich received degrees in Physics (honors) and Chemistry from Haverford College, and a Ph.D. in Oceanography from Scripps Institution of Oceanography in 1982. From 1982-83, he was an assistant professor at the Marine Sciences Research Center at the State University of New York. He joined the Jet Propulsion Laboratory in 1983, as a member of the Oceanography Group studying scatterometry and surface wave dynamics. He is a Principal Investigator and Coordinating Investigator on the ESA ERS-1 Science Working Team and, since 1983, has been Project Scientist for the NASA Scatterometer (NSCAT) Project. He chairs the NSCAT Science Working Team and is responsible for all science-related aspects of the NSCAT Project.

Co-Investigators

Robert M. Atlas, Goddard Space Flight Center
Robert A. Brown, University of Washington
Peter Cornillon, University of Rhode Island
David Halpern, Jet Propulsion Laboratory
Ross N. Hoffman, Atmospheric & Environmental Research, Inc.
Fuk Li, Jet Propulsion Laboratory
W. Timothy Liu, Jet Propulsion Laboratory
Richard K. Moore, University of Kansas
James J. O'Brien, Florida State University

SWIRLS

Stratospheric Wind Infrared Limb Sounder



EMPLOYS LIMB-VIEWING EOPM GAS CORRELATION AND FILTER RADIOMETRY IN SIX SPECTRAL CHANNELS

OBSERVES ATMOSPHERIC THERMAL EMISSION IN THE 7.6 TO 17.2 μM SPECTRAL INTERVAL

MEASURES FROM 82°N TO 82°S LATITUDE IN THE 20- TO 60-KM ALTITUDE RANGE

MAKES MEASUREMENTS WITH A SPATIAL RESOLUTION OF 200 KM CROSS-TRACK BY 350 KM ALONG-TRACK BY 3 KM VERTICAL

MEASURES WITH A PRECISION <5 M/SEC FOR WINDS, 1 TO 2K FOR TEMPERATURE, AND 10% FOR SPECIES

The SWIRLS investigation focuses on stratospheric structure, dynamics and transport, and the influence of natural and anthropogenic forcing on stratospheric change, including changes in ozone. The SWIRLS instrument measures continuous vertical profiles of wind, temperature, and the abundances of ozone and nitrous oxide in coincident fields-of-view. All measurements are made on both the day and night sides of the Earth, including the important winter polar night regions. Satellite measurements of temperature and species alone have proven inadequate for specification of transport in the stratosphere.

SWIRLS will provide the required direct measurements of wind by observing wind-induced Doppler shifts in atmospheric thermal emission spectrum of atmospheric nitrous oxide using a new gas correlation technique that employs electro-optic phase modulation (EOPM). EOPM gas correlation radiometry provides the high spectral selectivity needed to measure winds. The primary data products of the investigation will be daily, monthly, seasonal, and annual global maps of wind, temperature, abundances of ozone and nitrous oxide, as well as fluxes of heat, momentum, ozone, nitrous oxide, and dynamical quantities such as potential vorticity. ☆

FOR FURTHER INFORMATION:

McCleese, D.J. and J.S. Margolis, Remote sensing of stratospheric and mesospheric winds by gas correlation electro-optic phase modulation spectroscopy, *Applied Optics, 22,* 2528-2534, 1984.

SWIRLS Parameters

Measurement Approach

Six-channel limb-viewing radiometer:
- 7.8 and 8.6 µm (wind and N_2O)
- 8.9 and 9.7 µm (O_3)
- 15.4 and 16.5 µm (temperature and pressure)

Coverage and observation resolution:
- 82°N to 82°S latitude (both day and night)
- 20- to 60-km altitude range
- 3-km vertical resolution
- 200 (cross-track) x 350 (along-track) km horizontal resolution

Accommodation Issues

Mass: 150 kg
Duty cycle: 100%
Power: 250 W (average), 270 W (peak)
Data rate: 3 kbps
Thermal control: Stirling cycle coolers (detector); radiator, central thermal bus, and heaters (optics and electronics)
Thermal operating range: -53±1°C (optics bench)
Viewing directions: Four simultaneous views at ±45° and 135° and 135° with respect to spacecraft x-axis, all at 65° from nadir
Instrument IFOV: 0.9° (vertical) x 0.49° (horizontal)
Detector IFOV: 0.057° (vertical) x 0.49° (horizontal)
Pointing requirements (platform + instrument, 3σ):
- Control: 120 arcsec (x-axis), 2,700 arcsec (y-axis), and 3,900 arcsec (z-axis)
- Knowledge: 120 arcsec (x-axis), 60 arcsec (y-axis), and 36 arcsec (z-axis)
- Stability: 1.3 arcsec/sec (x-axis)

Physical size: 1.6 x 1.4 x 1.2 m

Principal Investigator—Daniel J. McCleese

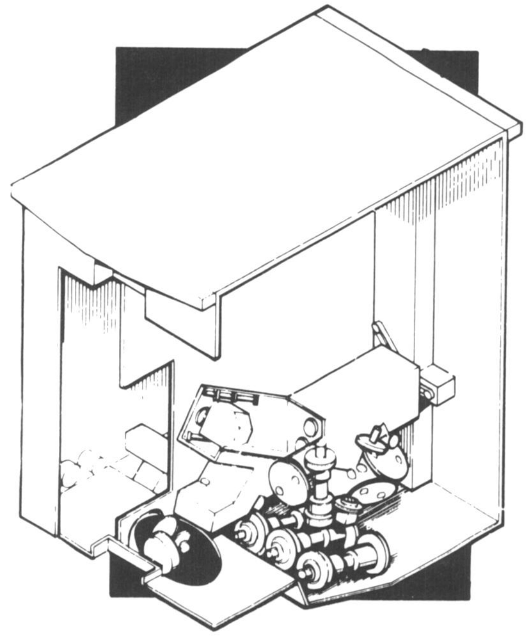
Daniel McCleese was a Fulbright Scholar at Oxford University, and earned a D.Phil. in Atmospheric Physics from that institution in 1976. He joined the Jet Propulsion Laboratory that same year, and is presently the Manager of the Earth and Space Science Division, an organization of over 300 researchers. Dr. McCleese is currently Principal Investigator on several SWIRLS-related investigations, including the Mars Observer Pressure Modulator Infrared Radiometer. He is well-published in the literature, and has been honored as a Fellow in the Royal Meteorological Society and with NASA recognition and group achievement awards.

Co-Investigators

Michael T. Coffey, National Center for Atmospheric Research
Lee S. Elson, Jet Propulsion Laboratory
Richard A. Heppner, Perkin-Elmer Corporation
John A. Pyle, University of Cambridge
David M. Rider, Jet Propulsion Laboratory
Richard B. Rood, Goddard Space Flight Center
John T. Schofield, Jet Propulsion Laboratory
Frederic W. Taylor, Oxford University

TES

TROPOSPHERIC EMISSION SPECTROMETER



HIGH SPECTRAL RESOLUTION INFRARED IMAGING FOURIER TRANSFORM SPECTROMETER

HERITAGE: ATMOS, SCRIBE

GENERATES 3-D PROFILES ON A GLOBAL SCALE OF VIRTUALLY ALL INFRARED-ACTIVE SPECIES FROM EARTH'S SURFACE TO THE LOWER STRATOSPHERE

SPECTRAL COVERAGE: 600-4350 CM^{-1} (2.3-16.7 μM)

SPECTRAL RESOLUTION: 0.025 CM^{-1}

MAXIMUM SAMPLING TIME OF 8 SEC, WITH A SIGNAL-TO-NOISE RATIO OF UP TO 600:1

LIMB MODE: HEIGHT RESOLUTION = 2.3 KM AND HEIGHT COVERAGE = 0-30 KM

TES is a high spectral resolution infrared imaging Fourier transform spectrometer with spectral coverage from 600-4,350 cm^{-1} (2.3-16.7 μm) and spectral resolution of 0.025 cm^{-1}. TES directly addresses four of the most pressing issues in global change: 1) The increase in gases implicated in greenhouse warming, 2) the increase of tropospheric ozone, 3) the precursors of acid rain, and 4) the exchange of gases with the stratosphere leading to stratospheric ozone depletion. These are all problems of tropospheric chemistry, and involve both the interaction of the atmosphere with the surface and the wide-ranging transport and reactivity of species in the free troposphere. TES has the capability to make both limb and down-looking observations. In the limb mode, TES has a height resolution of 2.3 km, with height coverage of 0-30 km. In the down-looking mode, TES has a spatial resolution of 50 x 5 km (global) and 5 x 0.5 km (local), with a swath of 50 x 180 km (global) and 5 x 18 km (local). Both limb and nadir sensing of thermal emission from the atmosphere and surface will be used to generate 3-D profiles on a global scale for retrievals of O_3, CO, CH_4, H_2O, and NOy from the surface to the lower stratosphere. These measurements will be assimilated into global circulation models to assess the current, and to predict the future, state of the lower atmosphere. ☆

FOR FURTHER INFORMATION:

Beer, R. and T.A. Glavich, Remote sensing of the troposphere by infrared emission spectroscopy, in *Advanced Optical Instrumentation for Remote Sensing of the Earth's Surface from Space,* vol. 1129, 42-51, Society of Photo-Optical Instrumentation Engineers, Bellingham, WA, 1989.

TES Parameters

Measurement Approach
High spectral resolution imaging Fourier transform spectrometer
Nadir and limb viewing
Spectral region 2.3 to 16.7μm, with four single-line arrays optimized for different spectral regions

Swath: n/a
Spatial resolution: 0.75 mrad x 7.5 mrad (narrow angle), 7.5 mrad x 75 mrad (wide angle)

Accommodation Issues
Mass: 333 kg
Duty cycle: <2% annually
Power: 516 W (operating), 568 W (peak), 316 W (average)
Data rate: 4.0925 Mbps (average operating), 15.617 Mbps (peak)
Thermal control by: Stirling cycle cooler, heater, central thermal bus, radiator
Thermal operating range: 0-30°C
FOV: +45° to -71° along-track, ±71° cross-track
Instrument IFOV: 0.75 mrad x 7.5 mrad (narrow angle), 7.5 mrad x 75 mrad (wide angle)
Pointing requirements (platform+instrument, 3σ):

Control:	144 arcsec
Knowledge:	144 arcsec
Stability:	15 arcsec per 32.8 sec
Jitter:	TBD

Physical size: 1.3 x 1.5 x 1.4 m

Principal Investigator—Reinhard Beer

Dr. Beer received a B.Sc. and Ph.D. in Physics from the University of Manchester, United Kingdom. He has been associated with the Jet Propulsion Laboratory since 1963; his current position is that of Senior Research Scientist and Supervisor of the Tropospheric Science Group, Earth and Space Sciences Division, and Manager of the Atmospheric and Oceanographic Sciences Section. Dr. Beer was chairman of the NASA Infrared Experiments Working Group and now serves as Co-Investigator on the ATLAS ATMOS experiment. He has been awarded the NASA Exceptional Scientific Achievement Medal for the discovery of extraterrestrial deuterium, three NASA group achievement awards, and numerous certificates of recognition.

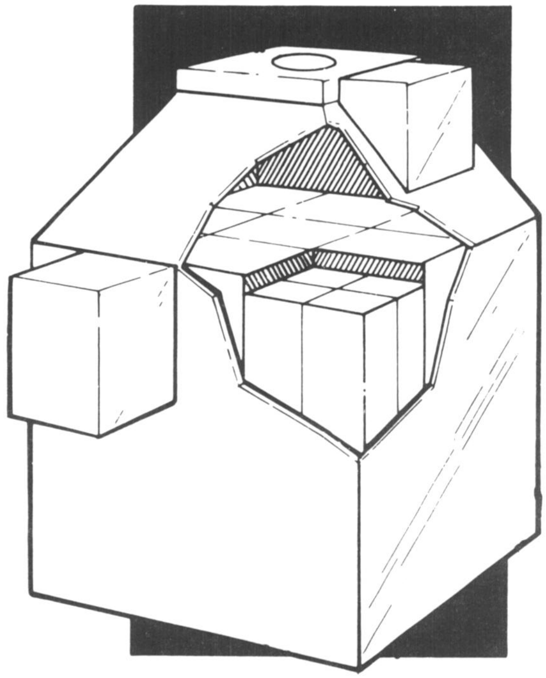
Co-Investigators

Carol J. Bruegge, Jet Propulsion Laboratory
Shepard A. Clough, Atmospheric & Environmental Research, Inc.
Daniel J. Jacob, Harvard University
Jennifer A. Logan, Harvard University
Jack S. Margolis, Jet Propulsion Laboratory
John V. Martonchik, Jet Propulsion Laboratory
David G. Murcray, University of Denver
Curtis P. Rinsland, Langley Research Center
Stanley P. Sander, Jet Propulsion Laboratory
Fredric W. Taylor, Oxford University
Steven C. Wofsy, Harvard University

XIE

X-RAY IMAGING

EXPERIMENT



X-RAY PINHOLE ANGER CAMERA WITH NAL (T1) AND PM DETECTORS FOR >20 KEV X-RAYS; PROPORTIONAL GAS-FILLED COUNTER FOR 3-20 KEV X-RAYS

OPTIONAL PARTICLE PACKAGE, ELECTROSTATIC ANALYZERS (FOR ELECTRONS AND PROTONS FROM A FEW EV TO 30 KEV), AND SOLID-STATE TELESCOPES FOR ELECTRONS (20 KEV TO A FEW MEV) AND PROTONS (20 KEV TO HUNDREDS OF MEV)

HERITAGE: X-RAY BALLOONS SINCE 1976; SIMILAR INSTRUMENT TO BE FLOWN BY CO-INVESTIGATORS ON SOVIET SPACECRAFT; PARTICLE DETECTORS ON AMPTE/GGS WIND/CLUSTER

FIELD-OF-VIEW: ±56° (X-RAYS), ±90° (PARTICLES)

DETECTS AND DETERMINES TOTAL PARTICULATE ENERGY PRECIPITATED INTO EARTH'S ATMOSPHERE

The objectives of XIE and the optional particle detectors are to detect and determine the total particulate energy that is precipitated into the Earth's atmosphere. The x-ray instrument system consists of a proportional gas-filled counter for detecting 3 to 20 keV x-rays, and an Anger camera for detecting and imaging 20 to 200 keV x-rays. The optional particle detector system consists of electrostatic analyzers and solid-state telescopes that will detect electrons from a few eV to a few MeV, and protons from a few eV to several hundred MeV. This combined package will provide information on the total x-ray fluxes impinging on the Earth's atmosphere; energy spectra of these x-rays; presence of different energy spectral components, including the hard x-ray components that reach the lower atmosphere near the tropopause; images of x-rays, which provide space and time information on their sources; and primary electron and ion distribution functions, from which macroscopic parameters such as density, convective velocities, and temperatures are obtained. These data will permit comprehensive modeling studies of thermodynamic, chemical, electrical, and meteorological effects on Earth due to the deposition of particle energy. ☆

FOR FURTHER INFORMATION:

Mauk, B.H., J. Chin, and G.K. Parks, Auroral x-ray images, *Journal of Geophysical Research*, *86*, 6827, 1981.

XIE Parameters

XIE Instrument

Measurement Approach
Nadir-looking proportional counter and pinhole camera

Swath: 2,000 km
Spatial resolution: 50-200 km

Accommodation Issues
Mass: 71 kg
Duty cycle: 70%
Power: 21 W (average), 34 W (peak)
Data rate: 5 kbps (average), 10 kbps (peak)
Thermal control by: Heater, radiator
Thermal operating range: 10-30°C
FOV and Instrument IFOV: ±56° from nadir (along-track and cross-track)
Pointing requirements (platform+instrument, 3σ):
- Control: 1°
- Knowledge: 1°
- Stability: 1°
- Jitter: 1°

Physical size: 63 x 49 x 58 cm

Optional Particle Detector

Measurement Approach
Electrostatic analyzers, solid-state detectors, and BGO scintillators

Swath: n/a
Spatial resolution: n/a

Accommodation Issues
Mass: 24 kg
Duty cycle: 90%
Power: 15 W
Data rate: 10 kbps (average), 70 kbps (peak)
Thermal control by: Heater, radiator
Thermal operating range: -50 to -20°C
FOV and Instrument IFOV: 15° x 300° (electrostatic analyzers), 30° x 180° (solid-state detectors and BGO scintillators)
Pointing requirements (platform+instrument, 3σ):
- Control: 1°
- Knowledge: 1°
- Stability: 1°
- Jitter: 1°

Physical size: 20 x 120 x 20 cm (stowed)
120 x 20 x 20 cm on a 1-m boom (deployed)

Principal Investigator—George K. Parks

George K. Parks received a B.A. and Ph.D. in Physics from the University of California, Berkeley. Dr. Parks spent 3 years as a Research Associate at the Physics Department of the University of Minnesota after earning his Ph.D. degree, and was Professeur Associate at the University of Toulouse, France, before he joined the faculty at the University of Washington, Seattle, in 1971. He is currently Professor in the Geophysics Program and Adjunct Professor in the Atmospheric Sciences and Physics Departments at that institution. Dr. Parks has worked on several past NASA missions, ATS-6 and ISEE, and is currently a Co-Investigator on the GGS/ISTP Program.

Co-Investigators

Charles W. Carlson, University of California, Berkeley
Richard Goldberg, Goddard Space Flight Center
Robert Lin, University of California, Berkeley
Paul Mandrou, Universite de Paul Sabatier
D. Ramsden, University of Southampton
Raymond G. Roble, National Center for Atmospheric Research
J.P. Treilhou, Universite de Paul Sabatier

EOS Interdisciplinary Science Investigations

Mark Abbott
Eric J. Barron
J. Ray Bates
Getulio T. Batista/
Jeffrey E. Richey
Peter G. Brewer
Josef Cihlar
Robert Dickinson
Jeff Dozier
William Grose
James E. Hansen
Graham Paul Harris *(Acting)*
Dennis L. Hartmann
Bryan L. Isacks
Yann H. Kerr/
Soroosh Sorooshian
William K.M. Lau
John LeMarshall
W. Timothy Liu
Berrien Moore III
Peter Mouginis-Mark
Masato Murakami
John A. Pyle
Drew Rothrock
David S. Schimel
Mark R. Schoeberl
Piers Sellers
Réjean Simard
Meric Srokosz
Byron D. Tapley
Bruce A. Wielicki

Coupled Atmosphere/Ocean Processes and Primary Production in the Southern Ocean

Principal Investigator—Mark Abbott

Dr. Abbott's investigation involves dynamics of the Southern Ocean—its circulation, biology, and interaction with the atmosphere—and proposes large-scale studies, including atmospheric forcing, ocean circulation, and primary production. In addition, techniques will be explored to cope with strong eddy activity in the Southern Ocean, and to incorporate inherently non-linear biological processes into physical models. There are two main goals: First, to understand the processes that regulate atmospheric and oceanic heat and momentum flux in the Southern Ocean, and how they vary in time and space; and second, to understand the temporal and spatial patterns of primary production, how they are regulated by physical forcing, and how these patterns are coupled with fluxes of biogenic carbon. This study will use pre-EOS measurements from U.S., Japanese, and European satellites, as well as EOS-era ocean and atmosphere measurements. Many of these data sets will be used in model development and in data assimilation models. In addition to models, this investigation will produce several data sets covering the Southern Ocean relevant for biogeochemical and physical climate studies.

Dr. Abbott has been involved in the fields of oceanography and ecology for 12 years. He received his undergraduate degree in Conservation of Natural Resources from the University of California at Berkeley, and a Ph.D. in Ecology from the University of California, Davis. He has been affiliated with Oregon State University since 1988, currently as Associate Professor in the College of Oceanography. Dr. Abbott has served on numerous EOS-related committees, including the EOS Science Steering Committee and the Moderate-Resolution Imaging Spectrometer (MODIS) Panel. His research interests include studies of coupled biological/physical processes in the upper ocean and phytoplankton photosynthesis. Dr. Abbott has been selected as a MODIS Team Member and is a member of the IGBP Coordinating Panel #2 on Marine Biosphere/Atmosphere Interactions. ☆

Co-Investigators

Andrew Bennett, Oregon State University
Dudley B. Chelton, Oregon State University
Steven Esbensen, Oregon State University
Gad Levy, Oregon State University
James Richman, Oregon State University
P. Ted Strub, Oregon State University
Andrew C. Thomas, Atlantic Center for Remote Sensing of the Ocean
Leonard J. Walstad, Oregon State University

Global Water Cycle: Extension Across the Earth Sciences

Principal Investigator—Eric J. Barron

This study focuses on the global water cycle to determine the scope of its interactions with all components of the Earth system, and to understand how it stimulates and regulates change on both global and regional scales. Dr. Barron plans to effect the conversion of patterns observed from space into knowledge of the processes that, linked together, determine the evolution of water in the Earth system. Research strategy involves developing a hierarchy of simulation models that assimilate EOS observations and produce information on physical and biological variables and process rates. The models will be tested with field studies that yield calibration and verification and, over the definition phase, will provide a methodology for resolving the presently unknown sources, sinks, and flux rates of the global water cycle. These will then be used to document significant aspects of the water cycle and to develop the knowledge necessary to understand past variations and predict them in the future.

Dr. Barron received M.S. and Ph.D. degrees in Oceanography and Climatology from the University of Miami, and was a postdoctoral fellow at NCAR. Dr. Barron joined Penn State as the Director of the Earth System Science Center and an Associate Professor of Geosciences in 1986. His research interests focus generally on global change and more specifically on numerical models of the climate system and the study of change throughout history. He is a member of numerous working groups related to these interests; in addition, he serves as Editor-in-Chief of *Paleogeography, Paleoclimatology, and Paleoecology*, and as Editor of *Global and Planetary Change*. ☆

Co-Investigators

Thomas Ackerman, Pennsylvania State University
Bruce Albrecht, Pennsylvania State University
Toby Carlson, Pennsylvania State University
John R. Christy, University of Alabama
Robert G. Crane, Pennsylvania State University
Kevin Furlong, Pennsylvania State University
Thomas Gardner, Pennsylvania State University
Steven J. Goodman, Marshall Space Flight Center
Lee R. Kump, Pennsylvania State University
Arthur Miller, Pennsylvania State University
Timothy L. Miller, Marshall Space Flight Center
Gary Petersen, Pennsylvania State University
Donna Peuquet, Pennsylvania State University
Franklin R. Robertson, Marshall Space Flight Center
Rudy Slingerland, Pennsylvania State University
Thomas Warner, Pennsylvania State University
Peter Webster, Pennsylvania State University
Brent Yarnal, Pennsylvania State University

The Development and Use of a Four-Dimensional Atmospheric/Ocean/Land Data Assimilation System for EOS

Principal Investigator—J. Ray Bates

Dr. Bates plans to develop and maintain a high-resolution, 4-D atmosphere/ocean/land data assimilation system for EOS. The project will involve research on all aspects of 4-D data assimilation (i.e., satellite retrievals, data quality control, objective analysis, initialization, and atmosphere/oceanic/land surface models), with dual objectives of extracting the maximum amount of knowledge possible from EOS data and building the foundation for a future "Earth System Model." Diagnostic studies will be carried out with the data produced by this assimilation system, emphasizing the global hydrological cycle and low-frequency atmospheric and oceanic variability. At the start of the EOS execution phase, the researchers hope the assimilation system will be capable of becoming the main vehicle for the delayed-mode production by EOSDIS of integrated atmosphere/ocean/land data sets in the horizontal scale of several tens of km.

J. Ray Bates has over 25 years of experience in meteorological research. A native of Ireland, Dr. Bates began his career with the Irish Meteorological Service and, after obtaining his Ph.D. degree at MIT in 1969, returned to that Service's Research Division. He has worked abroad on leave of absence on numerous occasions and has served as Senior Research Associate in the Department of Meteorology at the University of Maryland since 1987. He was appointed Head of the Global Modeling and Simulation Branch of the Laboratory for Atmospheres at GSFC in November 1989. Dr. Bates was awarded the Napier Shaw Memorial Prize of the Royal Meteorological Society in 1971, and was elected to membership of the Royal Irish Academy in 1986. ☆

Co-Investigators

Robert M. Atlas, Goddard Space Flight Center
Wayman E. Baker, NOAA/National Meteorological Center
Winston C. Chao, Goddard Space Flight Center
John Derber, NOAA/National Meteorological Center
Michael Fox-Rabinovitz, Goddard Space Flight Center
H. Mark Helfand, Goddard Space Flight Center
Donald R. Johnson, University of Wisconsin
Eugenia Kalnay, NOAA/National Meteorological Center
Masao Kanamitsu, NOAA/National Meteorological Center
Ants Leetmaa, NOAA/National Meteorological Center
James Pfaendtner, Goddard Space Flight Center
Chester F. Ropelewski, NOAA/National Weather Service
Yogesh C. Sud, Goddard Space Flight Center
Joel Susskind, Goddard Space Flight Center

Long-Term Monitoring of the Amazon Ecosystems Through EOS: From Patterns to Processes

Principal Investigator—Getulio T. Batista • Lead U.S. Co-Investigator—Jeffrey E. Richey

Amazonia is unique among terrestrial ecosystems for its spatial extent, the intimate interaction with the largest river on our planet, and the rate of change caused by human activity. Changes in the Amazon will certainly modify regional hydrology and chemistry; there is the potential to influence global climate patterns. Understanding the process dynamics of the Amazon system under natural conditions is of high scientific priority and is the essential prerequisite for modeling change. The goal of the program is to describe the routing of water and its chemical load from precipitation through the drainage system, to the mainstream and ocean, and back to the atmosphere under conditions of changing land use. Dr. Batista's group will emphasize modeling the land phase of the hydrologic cycle in undisturbed and deforested experimental basins, and will model eutrophication processes in the newly created reservoirs. Dr. Richey's group will emphasize regional-scale hydrologic modeling coupled to forest structure, biogeochemical cycling and sediment transport measurements, and models. Data for these studies will come from EOS sensors, climatological networks, and the field.

With a Ph.D. in Agronomy and Remote Sensing received from Purdue University in 1981, Dr. Batista has focused his research in the areas of crop identification and conditions assessment, yield prediction modeling, scene characteristics and classification accuracy, and crop field radiometry. Since 1971, he has been affiliated with the Instituto Nacional de Pesquisas Espaciais. He was the Head of the Remote Sensing Department from 1982 to 1987, Deputy Director of their Remote Sensing Directorate from 1985 to 1987, and recently was the Principal Investigator of the PEPS Program of the SPOT satellite for tropical agriculture.

Dr. Richey is a Professor of Oceanography at the University of Washington. He holds a B.A. in Biology from Stanford University, an M.S. in Environmental Engineering from the University of North Carolina, and a Ph.D in Ecology from the University of California, Davis. Dr. Richey is best known for work in ecosystem analysis and aquatic biogeochemistry. Since 1982, he has been Principal Investigator of the joint U.S./Brazil CAMREX project on the hydrology, biogeochemistry, and sediment transport of the Amazon River system; he has also been involved with the NASA SIR-B and ABLE missions. ☆

Co-Investigators

John B. Adams, University of Washington
Diogenes S. Alves, Instituto Nacional de Pesquisas Espaciais
Marcio N. Barbosa, Instituto Nacional de Pesquisas Espaciais
Thomas Dunne, University of Washington
Bruce R. Forsberg, Instituto Nacional de Pesquisas da Amazonia
Hermann Kux, Instituto Nacional de Pesquisas Espaciais
John Michael Melack, University of California, Santa Barbara
Luiz C.B. Molion, Instituto Nacional de Pesquisas Espaciais
Carlos Nobre, Instituto Nacional de Pesquisas Espaciais
Evlyn M.L.M. Novo, Instituto Nacional de Pesquisas Espaciais
Yosio E. Shimabukuro, Instituto Nacional de Pesquisas Espaciais
Joao Vianei Soares, Instituto Nacional de Pesquisas Espaciais
Compton J. Tucker, Goddard Space Flight Center
José C. Tundisi, Universidade de São Paulo
Dalton Valeriano, Instituto Nacional de Pesquisas Espaciais
Reynaldo L. Victoria, Universidade de São Paulo
John M. Wallace, University of Washington

Biogeochemical Fluxes at the Ocean/Atmosphere Interface

Principal Investigator—Peter G. Brewer

Dr. Brewer proposes to investigate the fate of solar radiation incident on the oceans with its pronounced chemical, physical, and biological consequences, and the feedback of the gaseous products of these interactions through the agency of wind, waves, and circulation to the marine atmosphere. Topics covered include oceanic photochemistry, pigments, ocean biological processes, surface slicks and chemical modification of surfaces, surface waves and momentum transfer, and biogenic gas fluxes and their linkage through models. The overarching theme is to derive Earth-scale constraints in these important processes through the combination of local data sets with satellite imagery. A further benefit will be the construction of global-scale views of critical processes from the complex interplay of field data and satellite observables. Cooperation with major field programs such as the Joint Global Ocean Flux Study (JGOFS) and World Ocean Circulation Experiment (WOCE) will be involved.

Dr. Brewer received his undergraduate and Ph.D. degrees from Liverpool University, and has over 20 years of experience in oceanography and marine chemistry. From 1967 to 1991, he was affiliated with the Woods Hole Oceanographic Institution (WHOI). In 1991, he was named President and Chief Executive Officer of the Monterey Bay Aquarium Research Institute. He is author or co-author of more than 70 scientific papers. From 1981 to 1983, he also was Program Director of Marine Chemistry at the National Science Foundation; in addition to teaching duties at WHOI, he chaired or served on numerous committees involved in marine research and global studies, as well as serving as editor or associate editor of related journals. Dr. Brewer's current research focuses on the global carbon cycle. He serves as Chairman of the U.S. Global Ocean Flux Study, and was past Vice Chairman of the International JGOFS. He is a Fellow of the American Geophysical Union. ☆

Co-Investigators

Neil V. Blough, Monterey Bay Aquarium Research Institute
Dennis Clark, NOAA/NESDIS
John W.H. Dacey, Woods Hole Oceanographic Institution
Wayne Esaias, Goodard Space Flight Center
Nelson M. Frew, Woods Hole Oceanographic Institution
David M. Glover, Woods Hole Oceanographic Institution
Catherine Goyet, Woods Hole Oceanographic Institution
Robert J. Olson, Woods Hole Oceanographic Institution
Edward T. Peltzer, Woods Hole Oceanographic Institution
Daniel J. Repeta, Woods Hole Oceanographic Institution
Anne M. Thompson, Goddard Space Flight Center
James A. Yoder, University of Rhode Island
Oliver C. Zafiriou, Woods Hole Oceanographic Institution

Northern Biosphere Observation and Modeling Experiment (NBIOME)

Principal Investigator—Josef Cihlar

Addressing issues related to the role of terrestrial vegetation at mid- and high-latitudes, this investigation builds on work accomplished or planned in Canada. It will carry out the research, development, and demonstration of a Northern Biosphere Information System (NBIS) to routinely monitor terrestrial vegetation from space. Initial model development, algorithm development, and output generation (e.g., a vegetation map of Canada) will be accomplished prior to EOS launch. EOS data will be optimized and applied over the Canadian land mass using the NBIS, and vegetation growth models will be developed to produce digital maps of net change in carbon storage for two different years after EOS launch. One or more succession models and digital maps of future vegetation distribution over Canada, based on observed or postulated changes in environmental conditions, will also be developed.

Dr. Cihlar holds degrees in Soil Science, Physical Geography, and Remote Sensing (Ph.D. from the University of Kansas, 1975), and has concentrated his research interests on renewable resources and data acquisition/analysis for land applications. He joined the Canada Centre for Remote Sensing (CCRS) as an Environmental Scientist in 1975. Since 1979, he has been responsible for applications development at CCRS. Dr. Cihlar is presently involved in planning the use of space observations for global change studies. He leads the Remote Sensing Technical Group reporting to the Royal Society of Canada, and is a member of the IGBP Working Group on Data and Information Systems. ☆

Co-Investigators

Francis J. Ahern, Canada Centre for Remote Sensing
Michael Apps, Canadian Forestry Service
Jean Beaubien, Canadian Forestry Service
Terry Carleton, University of Toronto
Raymond Desjardin, Central Experimental Farm
Peter Duinker, Lakehead University
Terry Fisher, Canada Centre for Remote Sensing
Bert Guindon, Canada Centre for Remote Sensing
Crawford Holling, University of Florida
Ken Lertzman, Simon Fraser University
Joe Lowe, Canadian Forestry Service
Philippe Teillet, Canada Centre for Remote Sensing

NCAR Project to Interface Modeling on Global and Regional Scales with Earth Observing System Observations

Principal Investigator—Robert Dickinson

Dr. Dickinson's study involves modeling, data analysis, data systems, and archiving, all directed toward improvements of global and mesoscale climate models at the National Center for Atmospheric Research (NCAR) for the purpose of improving prediction of global change. Sensitivity studies of the application of EOS data to model improvement will be carried out for several focused areas, including the land surface component in a global and regional context; the sea ice component; the role of clouds; and atmospheric profiles of latent heat release. EOS observations will be used to obtain global data sets to validate and provide boundary conditions to the models, and for improving parameterizations of key processes within the models. Also, he will perform long-term monitoring of atmospheric properties from operational satellite data, links between EOS sensor systems and model-generated fields, data visualization and archiving in the context of model requirements, maintenance of an EOS data archive, and exploration of new methodologies for organizing and archiving global data sets.

Dr. Dickinson was affiliated with NCAR since 1968, where he ultimately achieved the position of Deputy Director of the Climate and Global Dynamics Division. He is now with the University of Arizona. He is a member of the U.S. National Academy of Sciences and is active in efforts of the National Research Council, the American Geophysical Union, the International Geosphere-Biosphere Program, the World Climate Research Program, and the American Meteorological Society. He has over 150 refereed publications to his credit. He is a Fellow of the American Association for the Advancement of Science, the American Geophysical Union, and the American Meteorological Society (AMS), and was awarded the AMS Jule G. Charney Award in 1988. ☆

Co-Investigators

Richard E. Carbone, National Center for Atmospheric Research
James A. Coakley, Oregon State University
William Emery, University of Colorado
Ronald M. Errico, National Center for Atmospheric Research
John C. Gille, National Center for Atmospheric Research
Filippo Giorgi, National Center for Atmospheric Research
Dean Graetz, CSIRO
Robert D. Haskins, Jet Propulsion Laboratory
Ann Henderson-Sellers, Macquarie University
Roy L. Jenne, National Center for Atmospheric Research
Akira Kasahara, National Center for Atmospheric Research
Jeffrey T. Kiehl, National Center for Atmospheric Research
William A. Reiners, University of Wyoming
Kevin E. Trenberth, National Center for Atmospheric Research
Warren M. Washington, National Center for Atmospheric Research
Richard W. Zurek, Jet Propulsion Laboratory

Hydrology, Hydrochemical Modeling, and Remote Sensing in Seasonally Snow-Covered Alpine Drainage Basins

Principal Investigator—Jeff Dozier

The snow hydrology of alpine areas is an important component of the global hydrologic cycle, because of the large volumes of water stored in these reservoirs in the winter season, the sensitivity of the winter snowpack to climatic change, and the complex role of snow processes in acidic deposition. Alpine watersheds are particularly sensitive to damage from acidic deposition, because they are usually weakly buffered and their acid neutralizing capacities are limited. They are thus vulnerable to increasing acidic precipitation, both from increasing anthropogenic sources and from increased nucleation efficiencies caused by climatic warming. Understanding of the chemical and nutrient balances of such watersheds is difficult, however, because their hydrology is only partially understood and difficult to measure. Most of the water input comes from the winter snowfall, and field measurement programs are subject to problems from inclement weather and from avalanches. Ground and soil water are difficult to monitor because of spatial heterogeneity. The major objective of Dr. Dozier's multi-sensor, interdisciplinary investigation is a detailed understanding of the patterns and processes of water balance and chemical and nutrient balances of selected alpine watersheds throughout the world, including the Sierra Nevada of California, the Tien Shan of China, and the Oetztal Alpen in Austria. Data from several EOS instruments (i.e., MODIS, CERES, MISR, MIMR, HIRIS, and EOS SAR) will be used to monitor hydrologic conditions in the watersheds and to drive hydrologic models. In the intervening years, data will be obtained from the NASA aircraft program and from Landsat and SPOT. Hydrological and chemical sampling will be done in the field, and data will also be acquired from other programs that are currently investigating the effects of atmospheric pollutants on high-elevation watersheds, sponsored by the California Air Resources Board, Environmental Protection Agency, U.S. Geological Survey, and the National Park Service. The results will be extended spatially through combination with the hydrologic measurements.

With undergraduate and doctoral degrees in Geography (Ph.D. from the University of Michigan, 1973), Dr. Dozier has concentrated his research on alpine snow science and related studies in remote sensing, data and information systems, and radiative transfer. Since 1974, he has taught at the University of California, Santa Barbara (UCSB), where he is now Professor of Geography. Since June 1990, he has been on leave from UCSB to the NASA Goddard Space Flight Center, where he is the EOS Project Scientist. Dr. Dozier is also a HIRIS Team Member and chairs the Science Advisory Panel for EOS Data and Information. He recently completed service on the National Academy of Sciences' Committee on Opportunities in the Hydrologic Sciences, and just completed a 6-year term as Associate Editor of *Water Resources Research*. He now serves on the National Academy's Committee to Assess the Scope and Direction of Computer Science and Technology, and he began a 3-year term as Editor of *Geophysical Research Letters*. Dr. Dozier was recently elected a Fellow of the American Geophysical Union and is a Distinguished Visiting Scientist at the Jet Propulsion Laboratory. ☆

Co-Investigators

Roger C. Bales, University of Arizona
John M. Melack, University of California, Santa Barbara
Kathy A. Tonnessen, California Air Resources Board

Observational and Modeling Studies of Radiative, Chemical, and Dynamical Interactions in the Earth's Atmosphere

Principal Investigator—William Grose

Dr. Grose's team will provide increased understanding of the radiative, chemical, and dynamical processes that determine the circulation, thermal structure, and distribution of constituents of the Earth's atmosphere. Emphasis will be placed on examining interactive coupling among these processes. The investigation will be conducted through observational analysis and diagnostic interpretation of meteorological and constituent data from EOS instruments, in conjunction with satellite, balloon, ground-based, and aircraft data. Also, atmospheric simulation studies will be conducted with a hierarchy of models, incorporating radiative, chemical, and dynamical processes to varying degrees of complexity for the troposphere, stratosphere, and mesosphere.

William Grose received his M.S. in Physics from the College of William and Mary and a Ph.D. in Aerospace Engineering from Virginia Polytechnic Institute and State University. He is Senior Research Scientist and Assistant Head of the Theoretical Studies Branch, Atmospheric Sciences Division, at the Langley Research Center. He has participated in the development of several 3-D models for studies of atmospheric dynamics and transport. He is Principal Investigator for a current NASA modeling and observational analysis study, as well as Principal Investigator and member of the Upper Atmosphere Research Satellite (UARS) study team. Dr. Grose was a Visiting Scientist with the United Kingdom Universities' Atmospheric Modeling Group and the University of Reading, England. He was recipient of the NASA Medal for Exceptional Scientific Achievement in 1986. ☆

Co-Investigators

W. Thomas Blackshear, Langley Research Center
Richard S. Eckman, Langley Research Center
Duncan Fairlie, Langley Research Center
Rolando Garcia, National Center for Atmospheric Research
Alan O'Neill, British Meteorological Office
R. Bradley Pierce, Langley Research Center
Ellis E. Remsberg, Langley Research Center
Murry L. Salby, University of Colorado
Susan Solomon, U.S. Department of Commerce
Richard E. Turner, Langley Research Center

Interannual Variability of the Global Carbon, Energy, and Hydrologic Cycles

Principal Investigator—James E. Hansen

Dr. Hansen's team will investigate the interannual variability of key global parameters and processes in the global carbon cycle, the global thermal energy cycle, and the global hydrologic cycle. They will develop, analyze, and make available global geophysical data sets derived from pre-EOS and EOS observations. Developing data sets will involve use of observations in combination with global models that are already developed or under development. Analysis will involve studies of several specific interdisciplinary problems, each focused on interactions among components of the Earth system. Expected near-term products include knowledge of certain Earth system processes that can be investigated via large-scale interannual variability of a number of observed parameters; a mini EOS-type collection of data sets available in convenient form to other investigators; and improved definition of global measurement and data set needs for EOS.

Dr. Hansen heads the Goddard Institute for Space Studies (GISS). A student of Astronomy and Physics (Ph.D. from the University of Iowa, 1967), he has focused his research primarily on radiative transfer in planetary atmospheres and related interpretation of remote sounding, development of simplified climate models and 3-D global models, and the study of climate mechanisms. He has been involved on several photopolarimeter experiments such as AEROPOL, Voyager, Pioneer, and Galileo. In addition to his research and administrative duties at GISS, he serves as Adjunct Professor at Columbia University. Dr. Hansen is a well-known expert witness on current climate trends and has been instrumental in heightening awareness of humankind's impact on climate (i.e., the greenhouse effect). ☆

Co-Investigators

James K.B. Bishop, Columbia University
Barbara Carlson, Goddard Institute for Space Studies
Anthony Del Genio, Goddard Institute for Space Studies
Inez Fung, Goddard Institute for Space Studies
Andrew Lacis, Goddard Institute for Space Studies
Michael J. Prather, Goddard Institute for Space Studies
David H. Rind, Goddard Institute for Space Studies
William B. Rossow, Goddard Institute for Space Studies
Peter H. Stone, Massachusetts Institute of Technology

Interdisciplinary Studies of the Relationships Between Climate, Ocean Circulation, Biological Processes, and Renewable Marine Resources

Principal Investigator—Graham Paul Harris (Acting)

This investigation concerns a breadth of activities extending from basic to applied research, all of which are concerned with interannual variability in climate, biological processes, ocean-atmosphere interactions, and the marine fisheries resources. Dr. Harris plans to study the links between these processes in Australasian waters and fisheries. There is an important set of interactions to be examined between climatic El Niño Southern Oscillation (ENSO) events and ocean processes, as well as a need for studies of oceanic productivity in tropical waters and the subtropical convergence region south of Australia and New Zealand. Further examination of these interactions will be conducted using existing satellite data, data from new sensors, and EOS polar platform data. Suitable algorithms will be developed at all stages to measure phytoplankton biomass and productivity from space. At longer time scales, there is an important feedback between ocean productivity and global change, because the subtropical convergence region of the Southern Hemisphere is one of the most important sites of "new" production in the world ocean.

With academic preparation in Biology and Ecology (Ph.D. from Imperial College, London, 1969), Graham Harris has dedicated his career to the interaction of physical and biological processes, and their effect on aquatic resources. His work focused on the Great Lakes (Canada) from 1969 to 1983; his remote sensing career began with the ERTS-1 simulation missions. Since 1984, he has been affiliated with Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO) Divisions of Fisheries Research and Oceanography, first as Program Leader then Head of the Fisheries Remote Sensing Group. Dr. Harris chairs the Australian National Committee for Ocean Sciences; is Chair or member of numerous advisory committees and working groups on ocean remote sensing, including the Australian JGOFS committee; and is member of editorial boards of publications on marine ecology and oceanography. He is now Director of the CSIRO Office of Space Science and Applications, and a member of the International JGOFS science steering committee. ☆

Co-Investigators

John Church, Commonwealth Scientific and Industrial Research Organization
Richard Coleman, University of Sydney
Peter Craig, Commonwealth Scientific and Industrial Research Organization
George Cresswell, Commonwealth Scientific and Industrial Research Organization
Chris Fandrey, Commonwealth Scientific and Industrial Research Organization
J.S. Godfrey, Commonwealth Scientific and Industrial Research Organization
V. Lyne, Commonwealth Scientific and Industrial Research Organization
Trevor McDougall, Commonwealth Scientific and Industrial Research Organization
Gary Meyers, Commonwealth Scientific and Industrial Research Organization
Carl Nilsson, Commonwealth Scientific and Industrial Research Organization
M. Nunez, University of Tasmania
John Parslow, Commonwealth Scientific and Industrial Research Organization
Graeme I. Pearman, Commonwealth Scientific and Industrial Research Organization

Climate Processes Over the Oceans

Principal Investigator—Dennis L. Hartmann

The goal of Dr. Hartmann's investigation is to use data from various satellite instruments, data from other sources, and models to construct an integrated view of the atmospheric climate over the oceans. The physical processes considered will include boundary layer dynamics and resulting fluxes, cloud-scale and mesoscale dynamics, and cloud physics. Incorporation of the interactions between clouds and radiative fluxes and between scales of motion (i.e., from boundary layer turbulence to the largest scales of planetary motion) all prove necessary to achieve a comprehensive understanding of climate, enhancing researchers' ability to predict future change. Simultaneous measurements of a variety of physical variables that can be derived from EOS measurements will be utilized to better understand the atmosphere portion of the climate system and its interactions with the ocean.

Dennis Hartmann received his Ph.D. in Geophysical Fluid Dynamics from Princeton University in 1975. He has been on the faculty of atmospheric sciences at the University of Washington since 1977, and an adjunct faculty member of the Quaternary Research Center since 1978. His main research interests are in the areas of global climate, large-scale dynamics, and the radiative energy balance of the Earth; he has published over 50 research papers on these topics. Dr. Hartmann served as Principal Investigator in the Earth Radiation Budget Experiment (ERBE) and the Airborne Antarctic Ozone Experiment (AAOE) for which he received NASA Group Achievement awards. ☆

Co-Investigators

Robert A. Brown, University of Washington
Robert A. Houze, University of Washington
Kristina B. Katsaros, University of Washington
Conway B. Leovy, University of Washington

Tectonic/Climatic Dynamics and Crustal Evolution in the Andean Orogen

Principal Investigator—Bryan L. Isacks

Dr. Isacks employs the Andes Mountains (from equatorial regions to Patagonia) as a natural laboratory to study how tectonic processes of mountain building and volcanism interact with climate and hydrology to produce the landscape and its cover of soil and vegetation. The project includes two closely related components. The first is the determination of the past and present tectonic and erosional redistributions of crustal mass. The second is a comparison of the spatial pattern of climate and erosional fluxes during the present and during the Last Glacial Maximum. The basis for both components will be a comprehensive regional scale mapping of tectonics, topography, climate, hydrology, and land cover, all integrated into a geographic information system. The consequent data products will have direct application to the following global change efforts: 1) Modeling of land surface characteristics as the result of the interaction of climate and tectonics; 2) study of southern hemisphere quaternary climate history; 3) other EOS investigations requiring well-calibrated relationships between local to regional and global scale climate, hydrological, and land surface properties; and 4) identification of critical global change phenomena in a southern hemisphere continental mountain belt that can be effectively monitored from space.

Bryan L. Isacks received his Ph.D. in Seismology and Tectonics from Columbia University in 1965, joined the Cornell faculty in 1971, and is currently the William and Katherine Snee Professor of Geological Sciences and the Director of the Institute for the Study of the Continents. In 1981, Dr. Isacks initiated the Cornell Andes Project, a multidisciplinary approach to the study of a continental mountain belt. ☆

Co-Investigators

Richard Allmendinger, Cornell University
Arthur L. Bloom, Cornell University
Eric J. Fielding, Cornell University
Teresa Jordan, Cornell University
Suzanne M. Kay, Cornell University
William Philpot, Cornell University

The Hydrologic Cycle and Climatic Processes in Arid and Semi-Arid Lands

Principal Investigator—Yann H. Kerr • Lead U.S. Co-Investigator—Soroosh Sorooshian

Through the use of remotely sensed data, we now are able to monitor the responses to changes in hydrologic fluxes. With an effective linkage between remote sensing data and hydrologic models, we can obtain a better understanding of the processes that control the changes in hydrologic storages and fluxes. In this way, we may better assess the role of the hydrologic cycle in a global context and predict the effects of climatic or human-induced change.

Using several sites in the Sahel, Dr. Kerr's research focuses on quantifying and monitoring natural and anthropogenically induced changes in hydrologically relevant land surface parameters at the regional scale, and on improving the understanding of the Earth/atmosphere response to changes in land surface characteristics. A global data set will be defined and algorithms/models developed to yield geophysical parameters that would actually be used to monitor seasonal and year-to-year changes. These parameters would include surface temperature, roughness, moisture, vegetation characteristics, evapotranspiration, rainfall, shortwave incoming flux, and albedo. Soil-vegetation interactions and hydrologic feedback mechanisms will also be studied.

Dr. Sorooshian's research focuses initially on understanding hydrologic processes at the sub-watershed and watershed scale, then expanding to basin and regional scales. Data will be used to derive distributed basin characteristics as well as inputs to water/energy balance simulation models. These results will help to identify the dominant processes that control hydrologic fluxes at various spatial and temporal scales, and to develop improved hydrologic modeling and prediction capabilities during both storm and interstorm periods. The initial focus is on the Arizona-Sonoran desert of North America, and will later be extended to the African sites which are the focus of the Laboratoire d'Etudes et de Recherches en Télédétection Spatiale (LERTS) group.

Dr. Kerr received a Ph.D. from the Université P. Sabatier, Toulouse, France. From 1980 to 1985, he was with the Centre National d'Etudes Spatiales in Toulouse and, in 1985, joined the LERTS as a research scientist. During 1987 and 1988, he worked (on leave of absence) at the Jet Propulsion Laboratory. Dr. Kerr has worked mainly with AVHRR, METEOSAT, and Nimbus-7/SMMR data on the use of thermal infrared and passive microwaves for the determination of hydrological cycle parameters. He has been involved with several field experiments in Africa, as well as the 1987 EOS simultaneity experiment, and is a Principal Investigator for ERS-1 and MOS-1 EMDUP.

Dr. Sorooshian is Professor of Hydrology and Water Resources (and department head), and of Systems and Industrial Engineering, at the University of Arizona in Tucson. He holds an M.S. and Ph.D. in Systems Engineering and Water Resources Systems, respectively, from UCLA. Dr. Sorooshian is best known for his work on hydrologic modeling, specifically rainfallrunoff models, and the development of parameter estimation and calibration techniques. He has served as Principal Investigator of numerous projects related to hydrologic modeling, and is currently the Editor of *Water Resources Research*, published by the American Geophysical Union. ☆

Co-Investigators

Gerard Dedieu, LERTS
David C. Goodrich, USDA/Agricultural Research Service
Michael D. Hudlow, NOAA/National Weather Service
Alfredo R. Huete, University of Arizona
Jacques Imbernon, Institut de Recherche en Agronomie Tropicale
Ray D. Jackson, USDA/Agricultural Research Service
J.P. Lagouarde, Institut National de Recherche Agronomique
M. Susan Moran, USDA/Agricultural Research Service
Bernard Seguin, Institut National de Recherche Agronomique
Philip N. Slater, University of Arizona
James Smith, Princeton University
Mike Sully, University of Arizona
Alain Vidal, CEMAGREF-ENGREF
David Woolhiser, USDA/Agricultural Research Service

Global Hydrologic Processes and Climate

Principal Investigator—William K.M. Lau

The global water and energy cycle is an integral component of the Earth's climate. It provides the linkages between dynamic components of the land/ocean/atmosphere system. The goal of this investigation is to describe and understand the physical processes contributing to the mean and fluctuations of the global hydrologic and energy cycle. To achieve this goal, the investigators plan to focus on three closely linked scientific objectives aimed at improving our understanding of the following:

- The physical mechanisms of atmospheric hydrologic processes, in particular precipitation, and their interaction with the dynamics and radiative properties of the atmosphere
- The role of hydrologic processes in large-scale ocean/atmosphere/land interaction leading to natural fluctuation of the global climate system over a variety of time scales
- The role of land surface processes, including storage, in the global hydrologic cycle, with emphasis on the interaction and integration of regional and global scales.

This research project is designed to make extensive use of data collected from existing satellite missions and from EOS when they are available. Results obtained for the pre-EOS phase will be used to provide guidance for instrument design in the launch phase and to further our understanding of global hydrologic processes through model development and data analysis. A synergistic approach based on analysis of data from space and non-space platforms as well as modeling will be emphasized.

Dr. Lau received a Ph.D. in Atmospheric Sciences from the University of Washington in 1977. He was Assistant Professor at the Naval Postgraduate School until 1981. Since then, he has been Senior Research Meteorologist in the Laboratory for Atmospheres at the Goddard Space Flight Center. His areas of research expertise are climate dynamics, tropical and monsoon meteorology, and ocean-atmosphere interaction. He has published over 50 research papers in refereed literature, and is chairman of the American Meteorological Society Committee on Climate Variations. ☆

Co-Investigators

Robert F. Adler, Goddard Space Flight Center
John R. Bates, Goddard Space Flight Center
Thomas L. Bell, Goddard Space Flight Center
Wilfried H. Brutsaert, Cornell University
Bhaskar Choudhury, Goddard Space Flight Center
Prabhakara Cuddapah, Goddard Space Flight Center
Peter S. Eagleson, Massachusetts Institute of Technology
Edwin T. Engman, Goddard Space Flight Center
Marvin A. Geller, State University of New York, Stony Brook
Robert J. Gurney, University of Reading
H. Mark Helfand, Goddard Space Flight Center
N.C. Lau, NOAA/GFDL
W. Timothy Liu, Jet Propulsion Laboratory
Roger Lukas, University of Hawaii
John L. Monteith, International Crop Research Institute
Masato Murakami, Meteorological Research Institute
Abraham Oort, NOAA/GFDL
Sigfreid Schubert, Goddard Space Flight Center
Joanne Simpson, Goddard Space Flight Center
David O'C. Starr, Goddard Space Flight Center
Yogesh C. Sud, Goddard Space Flight Center
James A. Weinman, University of Wisconsin
Warren J. Wiscombe, Goddard Space Flight Center
Eric F. Wood, Princeton University
Man-Li C. Wu, Goddard Space Flight Center

The Processing, Evaluation, and Impact on Numerical Weather Prediction of AIRS, HMMR, MODIS, and LAWS Data in the Tropics and Southern Hemisphere

Principal Investigator—John LeMarshall

This investigation involves the development of processing algorithms and techniques to derive geophysical parameters of significance to atmospheric scientists from the AIRS, HMMR, MODIS-N, and LAWS instruments. It will also involve the development of a methodology for assimilation of these parameters into numerical weather prediction models, and an assessment of their utility in this context. Intercomparison studies with the satellite data will be performed. As a first step, the proposal involves research to derive sounding data from AMSU radiances that will be available in 1993, and the examination of the impact of these data in the southern hemisphere. Concurrently and later, research will be directed at producing a local processing capacity for the simulation, processing, and utilization of data from the AIRS and other EOS instruments cited, and for assimilation of the EOS processed data into numerical weather prediction (NWP) models.

Dr. LeMarshall received a Ph.D. in Physics from Monash University in 1972. He is Head of the Remote Sensing Group in the Bureau of Meteorology Research Centre in Melbourne, Australia. His specialties include remote sensing and data assimilation. Current activities include land, oceanic, and atmospheric application of AVHRR data, TOVS data, and geostationary meteorological satellite data. He manages and is responsible for the planning and policy development in both the operational and research areas of satellite meteorology in the Bureau of Meteorology. ☆

Co-Investigators

William P. Bourke, Bureau of Meteorology Research Centre
David Griersmith, Bureau of Meteorology Research Centre
Graeme A. Kelly, ECMWF
Lance Leslie, Bureau of Meteorology Research Centre
Graham Mills, Bureau of Meteorology Research Centre
Kamal K. Puri, Bureau of Meteorology Research Centre

The Role of Air-Sea Exchanges and Ocean Circulation in Climate Variability

Principal Investigator—W. Timothy Liu

Dr. Liu's investigation builds upon ongoing studies of climate change as related to the hydrological and energy balances of the coupled ocean-atmosphere system. Using the new capabilities of EOS sensors, synoptic time scale surface moisture, momentum, and heat fluxes over the global ocean will be computed. He and his team will examine the variabilities of various terms in the atmospheric energy and water budgets, and examine the interaction between different scales of atmospheric processes over oceans. The surface fluxes derived will be used to develop diagnostic models of the ocean's response to surface forcings. Eddy-resolving ocean general circulation models, including thermodynamics, with capabilities for assimilating EOS data will be developed to provide 3-D views of ocean circulation and heat storage.

W. Timothy Liu has been a Principal Investigator on studies concerning air-sea interaction and satellite remote sensing since he joined the Jet Propulsion Laboratory in 1979, and is currently the leader of the Air-Sea Interaction and Climate Team. He holds an M.S. and Ph.D. from the University of Washington. Dr. Liu has served on numerous science working groups and advisory committees for NASA, TOGA, WOCE, and JSC/CCCO, and is a Principal Investigator on both the NSCAT and TOPEX Science Investigation Teams. He has participated in many multi-national field experiments. He received the NASA Medal for Exceptional Scientific Achievement in 1990. ☆

Co-Investigators

Lee-Lueng Fu, Jet Propulsion Laboratory
Catherine Gautier, University of California, Santa Barbara
William R. Holland, National Center for Atmospheric Research
Paola Malanotte-Rizzoli, Massachusetts Institute of Technology
Pearn P. Niiler, Scripps Institution of Oceanography
William C. Patzert, Jet Propulsion Laboratory
Victor Zlotnicki, Jet Propulsion Laboratory

Changes in Biogeochemical Cycles

Principal Investigator—Berrien Moore III

The long-term goal of this investigation is to understand the primary biogeochemical cycles of the planet. The strategy is to study how element cycles function: 1) In quasi-steady state systems in the absence of human-induced perturbations, and 2) in the transient state induced by human-induced activity. The team will develop global, geographically specific, mathematical models and databases. These will describe ecosystem distribution and condition, the biological processes that determine the exchange of CO_2 and trace gases with the atmosphere, and the fluxes of carbon and nutrients to aquatic ecosystems. This suite of models will rest within an interactive information system that will integrate a geographic information system, a remote sensing system, a database management system, a graphics package, and a modern interface shell.

Dr. Moore earned his Ph.D. in Mathematics from the University of Virginia in 1969. He is best known internationally for his computer modeling of the global carbon cycle. Professor Moore's specific research interests include the application of geographic information systems and remote sensing in modeling ecosystem dynamics globally, and the use of inverse calculations to develop ocean models for use in carbon cycle investigations. He is well-published in ecosystems literature and in studies of the role of the ocean in the carbon cycle. He is involved in numerous related studies for NASA, the National Science Foundation, the Environmental Protection Agency, and the Department of Energy. Professor Moore is Director of the Institute for the Study of Earth, Oceans, and Space at the University of New Hampshire. ☆

Co-Investigators

John Aber, University of New Hampshire
William Emanuel, Oak Ridge National Laboratory
Robert C. Harriss, University of New Hampshire
Jerry M. Melillo, Marine Biological Laboratory
Bruce Peterson, Marine Biological Laboratory
Barrett N. Rock, University of New Hampshire
David Skole, University of New Hampshire
Charles Vorosmarty, University of New Hampshire

A Global Assessment of Active Volcanism, Volcanic Hazards, and Volcanic Inputs to the Atmosphere from the Earth Observing System

Principal Investigator—Peter Mouginis-Mark

Dr. Mouginis-Mark's investigation objectives are to understand the physical processes associated with volcanic eruptions, to assess the rate of injection and global dispersal of sulfur dioxide and other volcanic gases into the stratosphere (to study the influence of volcanism on climate), and to help investigate the role of volcanism in continental evolution. The investigation will draw upon many of the EOS sensors and will contribute significantly to the development of a near-real-time response capability for the different instruments via the production and distribution of algorithms suitable for the automatic searching of large data sets. Higher order data sets documenting each observed eruption or volcano will be the primary archival products, which will be transferred to the EOSDIS and also maintained locally for access by the volcanology community at large.

Academically trained in environmental sciences (Ph.D. from Lancaster University, England, 1977), Dr. Mouginis-Mark has concentrated his research experience on volcanic phenomena, planetary geology, and remote sensing. He has been associated with the University of Hawaii since 1982, and presently serves as both Associate Head of the Planetary Geosciences Division and as Professor in the Department of Geology and Geosciences. He has been actively involved in NASA planetary and Earth orbital missions, study groups, and working committees within his field of research. In addition, he has recently served as Associate Editor of *Geology* and as Editor of the Planetology Section of *EOS*. ✩

Co-Investigators

John B. Adams, University of Washington
Joy A. Crisp, Jet Propulsion Laboratory
Peter Francis, University of Hawaii
Jonathan Gradie, University of Hawaii
Kenneth Jones, Jet Propulsion Laboratory
Anne B. Kahle, Jet Propulsion Laboratory
Arlin Krueger, Goddard Space Flight Center
David Pieri, Jet Propulsion Laboratory
William I. Rose, Michigan Technological University
Steven Self, University of Hawaii
Louis S. Walter, Goddard Space Flight Center
Lionel Wilson, University of Hawaii
Robert S. Wolff, Apple Computers, Inc.
Charles A. Wood, University of North Dakota
Howard A. Zebker, Jet Propulsion Laboratory

Investigation of the Atmosphere/Ocean/Land System Related to Climatic Processes

Principal Investigator—Masato Murakami

Dr. Murakami's investigation provides a mixture of observational studies and climate modeling related to the atmosphere/ocean/land interactions through heat and momentum exchanges. His investigation consists of three components. First, researchers will develop algorithms for the objective identification of cloud types and the quantitative measurement of precipitation. Data validation of newly developed remote sensing techniques will also be carried out. Based on these products, observational studies will be conducted to examine the atmospheric system associated with various rainfall activities. It is also planned to investigate the role of atmospheric minor constituents in climate changes. Secondly, researchers will monitor climatic changes of the sea surface temperature, sea level, and surface wind through the use of satellite observations. This will lead to production of data sets that can be incorporated in the ocean modeling study of seasonal/interannual variations of the Pacific and the mid-latitudinal eddies of the ocean. Finally, researchers will examine land surface conditions, such as ground wetness and snow mass. An atmospheric general circulation model will be incorporated to evaluate the impact of anomalous surface conditions on climate change. Project components will exchange results and data with other components to ensure overall understanding of the Earth system.

Dr. Murakami was academically trained in Geophysics and Meteorology at the University of Tokyo, and earned his D.Sc. from that institution in 1974. Except for a 2-year position at Florida State University, Dr. Murakami has been affiliated with the Meteorological Research Institute for his entire professional career. Presently, he is Chief of Laboratory in the Typhoon Research Division. His research interests include tropical, monsoon, and satellite meteorology. ☆

Co-Investigators

Tadao Aoki, Meteorological Research Institute
Masahiro Endoh, Meteorological Research Institute
Toshifumi Fujimoto, Meteorological Research Institute
Masashi Fukabori, Meteorological Research Institute
Toshiro Inoue, Meteorological Research Institute
Masafumi Kamachi, Meteorological Research Institute
Y. Kitamura, Meteorological Research Institute
Akio Kitoh, Meteorological Research Institute
Yukio Makino, Meteorological Research Institute
Tetsuo Nakazawa, Meteorological Research Institute
Toru Sasaki, Meteorological Research Institute
Akira Shibata, Meteorological Research Institute
Kenzo Shuto, Meteorological Research Institute
Masato Sugi, Meteorological Research Institute
Tatsushi Tokioka, Meteorological Research Institute
Osamu Uchino, Meteorological Research Institute
Isamu Yagai, Meteorological Research Institute
Koji Yamazaki, Meteorological Research Institute

Chemical, Dynamical, and Radiative Interactions Through the Middle Atmosphere and Thermosphere

Principal Investigator—John A. Pyle

The objective of Dr. Pyle's research is to improve understanding of the atmospheric dynamical, chemical, and radiative interactions—hence the ability to predict and detect long-term atmospheric trends in the Earth's climatic and chemical environment. There will be a combined modeling and data analysis study by an interdisciplinary team of theoreticians looking at a variety of problems in the middle atmosphere and thermosphere. Specific topics will include the understanding of the circulation and internally generated variability of the atmosphere; interactions between chemical, dynamical, and radiative processes; and horizontal and vertical coupling mechanisms. The study will be a two-pronged theoretical assault using EOS data and sophisticated numerical, dynamical, radiative, photochemical models of the troposphere, stratosphere, and mesosphere now being developed in the United Kingdom.

Dr. Pyle holds a D.Phil. in Atmospheric Physics from the University of Oxford. Since 1985, he has been a University Lecturer in Physical Chemistry at the University of Cambridge. His research interests lie in the area of modeling and data analysis. Currently, he serves as Principal Investigator in the U.K. Universities Global Atmospheric Modeling Project supported by NERC. He is Chairman of the U.K. Stratospheric Ozone Review Group, and has served as a consultant to the European Space Agency on the future of middle atmospheric studies from space. In 1985, he was recipient of the Eurotrac Award of the Remote Sensing Society. ✩

Co-Investigators

Timothy J. Fuller-Rowel, University College, London
Lesley J. Gray, Rutherford Appleton Laboratory
Joanna D. Haigh, Imperial College of Science and Technology
Robert S. Harwood, University of Edinburgh
Brian Hoskins, University of Reading
R.L. Jones, University of Cambridge
Michael E. McIntyre, University of Cambridge
Roy J. Moffett, University of Sheffield
Shaun Quegan, University of Sheffield
David Rees, University College, London
Alan Rodger, British Antarctic Survey
Keith Shine, University of Reading

Polar Exchange at the Sea Surface (POLES): The Interaction of Oceans, Ice, and Atmosphere

Principal Investigator—Drew Rothrock

Dr. Rothrock will conduct an interdisciplinary program in the observation and scientific utilization of surface fluxes and conditions of both the ice-covered and ice-free polar oceans. Scientific research will focus on understanding the dynamics of the upper ocean and ice cover, which control the formation of the intermediate and deep water masses of the world ocean; on determining the atmospheric and oceanic processes that control the mass and momentum balance and extent of the sea ice cover; and on understanding the feedback by which variations in ice extent affect atmospheric and oceanic circulation. The program will require developing several models and algorithms, and combining them into a single model of the upper ocean, ice cover (where present), and atmospheric boundary layer.

Dr. Rothrock graduated summa cum laude from Princeton University in 1964, and earned his Ph.D. from the University of Cambridge in 1968. Since 1970, he has been affiliated with the University of Washington; since 1978, has been a Senior Research Scientist at that institution's Applied Physics Laboratory. He has concentrated his research entirely on sea ice dynamics and measurement, most specifically on the use of passive and active microwave observations. He is well represented in the current literature, and has served as Associate Editor for the *Journal of Geophysical Research*. He is a member of the Alaska SAR Facility (ASF) Science Team. ☆

Co-Investigators

Roger G. Barry, University of Colorado
Robert A. Brown, University of Washington
Frank Carsey, Jet Propulsion Laboratory
Jeffrey Key, University of Colorado
Seelye Martin, University of Washington
Michael Steele, University of Washington
Dale P. Winebrenner, University of Washington

Using Multi-Sensor Data to Model Factors Limiting Carbon Balance in Global Grasslands

Principal Investigator—David S. Schimel

Vegetation response to climate occurs through changing species composition and altered physiology. Dr. Schimel's group plans to couple a simple ecosystem model to spectral data from several EOS sensors to monitor changing patterns of physiology and ecosystem function in response to climate variability and directional change. The investigation's primary objective will be to develop and evaluate a simulation model of ecosystem controls over the water, energy, and biogeochemical cycles, including trace gas emissions, within semi-arid ecosystems worldwide. Analytical techniques and mixing models will be developed to separate the remotely sensed canopy signal from background. Canopy parameters will be used as inputs to the simulation model. Multi-temporal remote sensing will then be used to drive simulations of seasonal and interannual response to climate.

David Schimel received his Ph.D. in 1982, and has been on the Senior Staff of the Natural Resources Ecology Laboratory since 1983. He holds a joint appointment in the Department of Forest Sciences. His research addresses basic questions in biogeochemical cycling and the development of techniques for extrapolating rates of processes to landscape and regional scales. Dr. Schimel is involved with the International Geosphere-Biosphere Program (IGBP) in the areas of trace gas exchange and global ecosystem modeling. ☆

Co-Investigators

Steven Archer, Texas A&M University
Brian Curtiss, University of Colorado
Alexander F.H. Goetz, University of Colorado
Timothy Kittel, Colorado State University
William Parton, Colorado State University
Carol A. Wessman, University of Colorado

Investigation of the Chemical and Dynamical Changes in the Stratosphere Up to and During the EOS Observing Period

Principal Investigator—Mark R. Schoeberl

The purpose of this investigation is to characterize both anthropogenic and natural stratospheric changes. The main part of this effort consists of generating high-quality long-term data sets for stratospheric ozone, temperature, and trace gases starting with the Nimbus-7 measurements, continuing with UARS, and on through the EOS and UARS periods using forecast/assimilation techniques. The assimilation analyses will provide dynamically and chemically balanced global representations of satellite and ground-based data. The assimilated data will significantly improve the evaluation of trace constituent budgets and meteorological diagnostics, and will help characterize dynamical/chemical/radiative interactions in the stratosphere.

Mark Schoeberl received his M.S. and Ph.D. from the University of Illinois. He has 15 years of research experience in atmospheric dynamics, stratospheric physics, and numerical modeling. Dr. Schoeberl has been affiliated with NASA/Goddard Space Flight Center since 1983, and is presently with the Atmospheric Chemistry and Dynamics Branch. Within his field of research, Dr. Schoeberl has chaired conferences and committees or served in an editorial capacity on numerous occasions. He is a recipient of the Naval Research Laboratory (NRL) Publication Award and NASA Technical and Group Achievement Awards. ☆

Co-Investigators

Anne R. Douglass, Goddard Space Flight Center
Marvin A. Geller, State University of New York, Stony Brook
Robert D. Hudson, University of Maryland, College Park
Charles H. Jackman, Goddard Space Flight Center
Jack A. Kaye, Goddard Space Flight Center
Leslie Robert Lait, Goddard Space Flight Center
Paul A. Newman, Goddard Space Flight Center
James Pfaendtner, Goddard Space Flight Center
Richard B. Rood, Goddard Space Flight Center
Joan E. Rosenfield, Goddard Space Flight Center
Richard S. Stolarski, Goddard Space Flight Center
Anne M. Thompson, Goddard Space Flight Center

Biosphere-Atmosphere Interactions

Principal Investigator—Piers Sellers

Dr. Sellers' research will focus on the interaction between the land surface and the atmosphere, stressing the biospheric exchanges of energy, water, and carbon. The scope of the investigation will be global, and will combine an extended time series of remote sensing data with interpretive models and a realistic combined model of the terrestrial biosphere and the global atmosphere. Related work will focus on terrestrial ecosystem processes, particularly the use of models driven by satellite data. In carrying out this research, his team hopes to achieve some broader goals. In addition to improving the understanding of the critical components of the Earth system, the research will yield new and improved products of derived surface and atmospheric parameters, and will be directly useful in developing methodologies to extract maximum benefit from EOS.

Piers Sellers is an honors graduate of Edinburgh University, and received his Ph.D. from Leeds University in 1981. He has over 11 years of experience in the fields of natural and environmental resources, computer systems analysis, computer simulation, atmosphere/biosphere interactions, and remote sensing and meteorology. Dr. Sellers is based at NASA/Goddard Space Flight Center, Biospheric Sciences Branch. He has been extensively involved with the International Satellite Land Surface Climatology Project (ISLSCP), serving as Staff Scientist for the First ISLSCP Field Experiment (FIFE). ☆

Co-Investigators

Joe Berry, Carnegie Institution
Christopher Field, Carnegie Institution
Inez Fung, Goddard Institute for Space Studies
Christopher O. Justice, Goddard Space Flight Center
Pamela A. Matson, Ames Research Center
Harold Mooney, Stanford University
David A. Randall, Colorado State University
Compton J. Tucker, Goddard Space Flight Center
Susan Ustin, University of California, Davis
Peter Vitousek, Stanford University

Use of a Cryospheric System (CRYSYS) to Monitor Global Change in Canada

Principal Investigator—Réjean Simard

The polar regions are particularly important in monitoring the effects of global change upon the environment. Changes in the atmosphere affect sea ice, land ice, permafrost, and snow cover, which in turn create fluctuations in the atmosphere, oceans, and freshwater. In order to effectively model the global climate, both the long-term and the short-term records must be established and interpreted. Long-term information comes from the reconstruction of past climates using such sources as ice cores from glaciers and ice caps, and from borehole records in permafrost. Short-term information is provided by climatological databases and remote sensing sources. The compatibility of these data records and their accessibility must also be established. This includes the verification of remote sensing techniques, and determining the utility of these observations for use in environmental change studies.

The CRYSYS group will develop and validate the models necessary for using cryospheric information in the evaluation, understanding, and monitoring of the effects of global change. This will be accomplished by maintaining an extensive array of field sites in critical areas, and by developing algorithms for the extraction of geophysical variables for use in the initialization and validation of local, regional, and polar models.

Dr. Simard received a Ph.D. in Geophysics from the University of Lausanne in 1980. He has been a research scientist at the Canada Center for Remote Sensing (CCRS) since that time. Since 1987, he has also been an adjunct professor at CARTEL remote sensing laboratory of Sherbrooke University. His experience includes remote sensing, geophysics, and natural resources studies. He has been Principal Investigator for the PEPS program, evaluating the SPOT-1 satellite system for production of digital terrain models and geoscience-related applications. ☆

Co-Investigators

Francis Bowkett, Canadian Climate Centre
Melinda Brugman, National Hydrology Research Institute
Josef Cihlar, Canada Centre for Remote Sensing
Demetris Delikaraoglou, Canada Centre for Surveying
John Falkingham, Canadian Ice Centre
Terry Fisher, Canada Centre for Remote Sensing
Hugh French, University of Ottawa
Barry Goodison, Canadian Climate Centre
Hardie Granberg, University of Sherbrooke (CARTEL)
Allen Judge, Geological Survey of Canada
Roy Koerner, Geological Survey of Canada
Robert Leconte, Canada Centre for Remote Sensing
Ellsworth LeDrew, University of Waterloo (EOL)
Marlon Lewis, Dalhousie University
Michael Manore, Canada Centre for Remote Sensing
Barry Maxwell, Canadian Climate Centre
Marie-Catherine Mouchot, Canada Centre for Remote Sensing
Lawrence Mysak, McGill University (C2GCR)
Simon Ommaney, National Hydrology Research Institute
Terry Prowse, National Hydrology Research Institute

Middle and High Latitudes Oceanic Variability Study (MAHLOVS)

Principal Investigator—Meric A. Srokosz

Much effort is presently being expended on determining the long-term and large-scale means and trends in the structure of the oceans. Stressing the importance of understanding variability as well, Dr. Srokosz plans to build on ongoing and planned field work to examine the spatial and temporal variability of the eastern North Atlantic and Southern Oceans. MAHLOVS will make significant use of the microwave, visible, and infrared EOS sensors to investigate the variability of the atmospheric forcing of the oceans, the consequent effect on oceanic response, and the resulting effect on the oceans' biological productivity. These data will be combined in a synergistic manner and assimilated into an ocean model; the result will be statistical descriptions of the temporal and spatial variability of the atmosphere-ocean biology system, and their interrelationships on space scales ranging from 1 to 1,000 km and time scales of days to years.

Meric Srokosz has 11 years of experience in the fields of applied mathematics, remote sensing of oceans, and radar altimetry. He holds both undergraduate and doctoral degrees in Mathematics from Bristol University. Currently, he serves on the NERC Remote Sensing Applications Development Unit of the British National Space Center, where he is responsible for coordination of United Kingdom activities in remote sensing of the oceans, and development of applications and research on remote sensing of the oceans. Dr. Srokosz is a Principal Investigator for the ERS-1 mission and Co-Investigator on the TOPEX/Poseidon and SIR-C missions. ☆

Co-Investigators

Peter G. Challenor, James Rennell Centre for Ocean Circulation
Mike Fasham, James Rennell Centre for Ocean Circulation
Trevor Guymer, James Rennell Centre for Ocean Circulation
John Marshall, Imperial College of Science and Technology
Ian Robinson, University of Southampton
Peter K. Taylor, James Rennell Centre for Ocean Circulation

Earth System Dynamics: The Determination and Interpretation of the Global Angular Momentum Budget Using the Earth Observing System

Principal Investigator—Byron D. Tapley

The goal of this investigation is to develop appropriate system models to use the multi-sensor contribution from EOS in combination with other satellite and in situ data. This approach will allow researchers to investigate the relationship between the atmosphere, oceans, and solid Earth, and the exchange of energy and angular momentum between these components of the Earth's dynamic system. Specific objectives include understanding the contribution of air, water, and atmospheric motion to Earth rotation variations and related angular momentum exchange; establishing a Terrestrial Reference System for monitoring tectonic and global sea level change over multiple decades; and understanding how mountain torques and surface friction couple angular momentum variations of the oceans, atmosphere, and solid Earth.

Dr. Tapley earned his Ph.D. in Engineering Mechanics at the University of Texas, Austin, and has over 30 years of experience in aerospace engineering. He began teaching at his alma mater in 1958. Since 1984, he has held the Clare Cockrell Williams Centennial Chair in the Department of Aerospace Engineering and Engineering Mechanics, and he serves as Director of the Center for Space Research. His research interests focus on the application of nonlinear parameter estimation methods to determine crustal motion, Earth rotation, the Earth's geopotential, and ocean circulation. He has served on numerous NASA advisory committees, including SESAC and the EOS Science Steering Committee. He has served as Chairman of the Geodesy Section for the American Geophysical Union. He received the NASA Exceptional Scientific Achievement Medal in 1983, and the AIAA Mechanics and Control of Flight Award in 1989. He is a member of the National Academy of Engineering, and a Fellow of AGU, AIAA, and AAS. ☆

Co-Investigators

Richard Eanes, University of Texas, Austin
John Lundberg, University of Texas, Austin
Rui M. Ponte, Atmospheric & Environmental Research, Inc.
Richard D. Rosen, Atmospheric & Environmental Research, Inc.
David A. Salstein, Atmospheric & Environmental Research, Inc.
Bob E. Schutz, University of Texas, Austin
C.K. Shum, University of Texas, Austin
Clark R. Wilson, University of Texas, Austin

An Interdisciplinary Investigation of Clouds and Earth's Radiant Energy System: Analysis (CERES-A)

Principal Investigator—Bruce A. Wielicki

Dr. Wielicki's investigation will provide EOS with a consistent database of accurately known fields of radiation and cloud properties. Radiative data will be provided as fluxes at the top of the Earth's atmosphere, at the Earth's surface, and as flux divergences within the atmosphere. Cloud properties will be provided as measured areal coverage, cloud altitude, shortwave and longwave optical depths, cloud particle size, and condensed water density. The large systematic diurnal variations of radiation and clouds will be resolved by analyzing data from three spacecraft: NASA and ESA polar platforms, and from the Japanese platform employing a 55° inclined orbit. The combination of these data with global climate model studies will allow the determination of the interaction of clouds with the Earth's climate, a critical issue for understanding global change. Pre-launch studies of CERES-A radiative transfer models and data analysis algorithms will use existing satellite data (AVHRR/HIRS/ERBE) along with field measurements of clouds and radiation collected during the First ISCCP Regional Experiment (FIRE).

Dr. Wielicki was awarded a Ph.D. in Physical Oceanography from the Scripps Institution of Oceanography in 1980. He has focused primarily on atmospheric research concerning cloud properties, cloud retrieval, and the Earth radiation budget. Following a 3-year assignment with NCAR, Dr. Wielicki joined NASA/Langley Research Center as Research Scientist in 1980. While there, he served as Principal Investigator on the Landsat Thematic Mapper science team. Ongoing investigations include work as Co-Investigator on the Earth Radiation Budget Experiment (ERBE), and roles as Project Scientist and Principal Investigator for FIRE. ☆

Co-Investigators

Bruce R. Barkstrom, Langley Research Center
Maurice L. Blackmon, NOAA/Environmental Research Laboratory
Robert D. Cess, State University of New York
Thomas P. Charlock, Langley Research Center
James A. Coakley, Oregon State University
Dominique Crommelynck, Royal Meteorological Institute, Belgium
Wayne L. Darnell, Langley Research Center
Richard N. Green, Langley Research Center
Edwin F. Harrison, Langley Research Center
Robert S. Kandel, Ecole Polytechnique
Michael D. King, Goddard Space Flight Center
Robert B. Lee III, Langley Research Center
Alvin J. Miller, NOAA/National Meteorological Center
Patrick Minnis, Langley Research Center
V. Ramanathan, Scripps Institution of Oceanography
David Randall, Colorado State University
G. Louis Smith, Langley Research Center
Larry L. Stowe, NOAA/NESDIS
John T. Suttles, Langley Research Center
Ronald M. Welch, South Dakota School of Mines & Technology

EOS Points of Contact

Mark R. Abbott
Oregon State University
College of Oceanography
Oceanography Administration, Building 104
Corvallis, OR 97331-5503
Telemail: MABBOTT/GSFCMAIL

Wayman E. Baker
NOAA/NMC
Development Division
World Weather Building, Rm 204
Washington, DC 20233
Telemail: WBAKER/GSFCMAIL

Bruce R. Barkstrom
Langley Research Center
Mail Stop 420
National Aeronautics and Space Administration
Hampton, VA 23665-5225
Telemail: BRBARKSTROM/NASAMAIL

John Barnett
Oxford University
Atmospheric, Oceanic and
Planetary Sciences
Clarendon Laboratory
Oxford, OX1 3PU
UNITED KINGDOM
Telemail: JBARNETT/GSFCMAIL

Eric J. Barron
Pennsylvania State University
Earth System Science Center
248 Deike Building
University Park, PA 16802
Telemail: E.BARRON/OMNET

John R. Bates
Goddard Space Flight Center
Code 911
National Aeronautics and Space Administration
Greenbelt, MD 20771
Telemail: JBATES/GSFCMAIL

Getulio T. Batista
Goddard Space Flight Center
Mail Code 923
National Aeronautics and Space Administration
Greenbelt, MD 20771

Reinhard Beer
Jet Propulsion Laboratory
Mail Stop 183-301
4800 Oak Grove Drive
Pasadena, CA 91109
Telemail: RBEER/GSFCMAIL

Peter G. Brewer
Monterey Bay Aquarium Research Institute
160 Central Avenue
Pacific Grove, CA 93950
Telemail: P.BREWER/OMNET

Rhett Butler
Incorporated Res. Inst. for Seismology
1616 N. Ft. Myer Drive, Suite 1440
Arlington, VA 22209

Moustafa T. Chahine
Jet Propulsion Laboratory
Mail Stop 180-904
4800 Oak Grove Drive
Pasadena, CA 91109
Telemail: MCHAHINE/NASAMAIL

Hugh J. Christian
Marshall Space Flight Center
Mail Stop ES43
National Aeronautics and Space Administration
Huntsville, AL 35812
Telemail: HCHRISTIAN/NASAMAIL

Josef Cihlar
Canada Centre for Remote Sensing
Applications Development
1547 Merivale Road, 4th Floor
Ottawa, Ontario K1A 0Y7
CANADA
Telemail: JCIHLAR/GSFCMAIL

Robert E. Dickinson
University of Arizona
Dept. of Atmospheric Sciences
Room 542, PAS Building
Tucson, AZ 85721
Telemail: R.DICKINSON/OMNET

David J. Diner
Jet Propulsion Laboratory
Mail Stop 169-237
4800 Oak Grove Drive
Pasadena, CA 91109
Telemail: DJDINER/NASAMAIL

Jeff Dozier
Goddard Space Flight Center
Code 900
National Aeronautics and Space Administration
Greenbelt, MD 20771
Telemail: JDOZIER/NASAMAIL

James R. Drummond
University of Toronto
Department of Physics
60 George Street
Toronto, Ontario M5S 1A7
CANADA
Telemail: JDRUMMOND/GSFCMAIL

Charles Elachi
Jet Propulsion Laboratory
Mail Stop 180-703
4800 Oak Grove Drive
Pasadena, CA 91109
Telemail: CELACHI/NASAMAIL

Michael H. Freilich
Jet Propulsion Laboratory
Mail Stop 300-323
4800 Oak Grove Drive
Pasadena, CA 91109
Telemail: M.FREILICH/OMNET

Lee-Lueng Fu
Jet Propulsion Laboratory
Mail Stop 300-323
4800 Oak Grove Drive
Pasadena, CA 91109
Telemail: L.FU/OMNET

John C. Gille
National Center for Atmospheric Research
Atmospheric Chemistry Division
PO Box 3000
1850 Table Mesa Drive
Boulder, CO 80307-3000
Telemail: JGILLE/GSFCMAIL

Alexander F.H. Goetz
University of Colorado
CSES/CIRES
Campus Box 449
Boulder, CO 80309-0449
Telemail: AGOETZ/NASAMAIL

William L. Grose
Langley Research Center
Mail Stop 401B
National Aeronautics and Space Administration
Hampton, VA 23665-5225
Telemail: WLGROSE/NASAMAIL

James Hansen
Goddard Institute for Space Studies
National Aeronautics and Space Administration
2880 Broadway, New York, NY 1002
Telemail: JHANSEN/GSFCMAIL

Graham P. Harris
CSIRO
Office of Space Science and Applications
PO Box 225
Dickson, ACT 2602
AUSTRALIA
Telemail: GPHARRIS/GSFCMAIL

Dennis L. Hartmann
University of Washington, Seattle
Department of Atmospheric Science, AK-40
Seattle, WA 98195
Telemail: DHARTMANN/GSFCMAIL

Roderick A. Heelis
University of Texas, Dallas
PO Box 688
Richardson, TX 75083
Telemail: RHEELIS/GSFCMAIL

Bryan L. Isacks
Cornell University
INSTOC
Snee Hall
Ithaca, NY 14853
Telemail: BISACKS/GSFCMAIL

Anne B. Kahle
Jet Propulsion Laboratory
Mail Stop 183-501
4800 Oak Grove Drive
Pasadena, CA 91109
Telemail: SEC.326/J.P.L.

Yann H. Kerr
LERTS
18 Avenue Edouard Belin
Toulouse, Cedex 31055
FRANCE
Telemail: Y.KERR/OMNET

Robert A. Langel
Goddard Space Flight Center
Code 922
National Aeronautics and Space Administration
Greenbelt, MD 20771
Telemail: RLANGEL/GSFCMAIL

William K.M. Lau
Goddard Space Flight Center
Code 913
National Aeronautics and Space Administration
Greenbelt, MD 20771
Telemail: WLAU/GSFCMAIL

John Francis LeMarshall
Bureau of Meteorology Research Centre
Satellite Section
GPO Box 1289
Melbourne, Victoria 3001
AUSTRALIA
Telemail: BMRC.AUSTRALIA/OMNET

W. Timothy Liu
Jet Propulsion Laboratory
Mail Stop 300-323
4800 Oak Grove Drive
Pasadena, CA 91109
Telemail: T.LIU/OMNET

Daniel J. McCleese
Jet Propulsion Laboratory
Mail Stop 183-335
4800 Oak Grove Drive
Pasadena, CA 91109
Telemail: DMCCLEESE/NASAMAIL

M. Patrick McCormick
Langley Research Center
Mail Stop 475
National Aeronautics and Space Administration
Hampton, VA 23665-5225
Telemail: MPMCCORMICK/NASAMAIL

William G. Melbourne
Jet Propulsion Laboratory
Mail Stop 238-540
4800 Oak Grove Drive
Pasadena, CA 91109
Telemail: WMELBOURNE/J.P.L.

Berrien Moore III
University of New Hampshire
Science & Eng. Research Bldg.
Institute for the Study of
Earth, Oceans, and Space
Durham, NH 03824-3525
Telemail: B.MOORE.UNH/OMNET

Peter Mouginis-Mark
University of Hawaii, Manoa
Planetary Geosciences Division
Hawaii Institute of Geophysics
2525 Correa Road
Honolulu, HI 96822
Telemail: P.MOUGINIS.MARK/OMNET

Masato Murakami
Meteorological Research Institute
Typhoon Research Institute
1-1 Nagamine
Ibaraki-ken, Tsunited kingdomuba-shi 305
JAPAN
Telemail: M.MURAKAMI/MRI

George K. Parks
University of Washington
Department of Geophysics, AK50
Seattle, WA 98195
Telemail: CASTOR::GPARKS::SPAN

John Adrian Pyle
University of Cambridge
Department of Chemistry
Lensfield Road
Cambridge, CB2 1EW
UNITED KINGDOM
Telemail: JPYLE/GSFCMAIL

Jeffrey E. Richey
University of Washington
School of Oceanography, WB-10
Seattle, WA 98195
Telemail: J.RICHEY/OMNET

Drew Rothrock
University of Washington
Applied Physics Laboratory
Polar Science Center
1013 NE 40th Street
Seattle, WA 98105
Telemail: D.ROTHROCK/OMNET

Gary J. Rottman
University of Colorado
Laboratory for Atmospheric
and Space Physics
Campus Box 392
Boulder, CO 80309-0392
Telemail: GROTTMAN/GSFCMAIL

James M. Russell
Langley Research Center
Mail Stop 401B
National Aeronautics and Space Administration
Hampton, VA 23665-5225
Telemail: JMRUSSELL/NASAMAIL

Vincent V. Salomonson
Goddard Space Flight Center
Code 900
National Aeronautics and Space Administration
Greenbelt, MD 20771
Telemail: VSALOMONSON/GSFCMAIL

David S. Schimel
University Center for Atmospheric Res.
Climate System Modeling
Program
PO Box 3000
Boulder, CO 80307-3000
Telemail: DSCHIMEL/GSFCMAIL

Mark R. Schoeberl
Goddard Space Flight Center
Code 916
National Aeronautics and Space Administration
Greenbelt, MD 20771
Telemail: MSCHOEBERL/GSFCMAIL

Bob E. Schutz
University of Texas, Austin
Center for Space Research
WRW 402
Austin, TX 78712-1085
Telemail: BSCHUTZ/GSFCMAIL

Piers Sellers
Goddard Space Flight Center
Code 923
National Aeronautics and Space Administration
Greenbelt, MD 20771

Rejean Simard
Canada Centre for Remote Sensing
2464 Sheffield Road
Ottawa, Ontario K1A 0Y7
CANADA

Soroosh Sorooshian
University of Arizona
Department of Hydrology and
Water Resources
Old Geology Building
Tucson, AZ 85721
Telemail: SOROOSH@ARIZRVA/BITNET

Roy Spencer
Marshall Space Flight Center
Mail Stop E543
National Aeronautics and Space Administration
Huntsville, AL 35812
Telemail: RSPENCER/NASAMAIL

Meric A. Srokosz
James Rennell Centre for Ocean Circ.
Chilworth Research Centre
Gamma House
Chilworth, Southampton S01 7NS
UNITED KINGDOM
Telemail: MSROKOSZ/GSFCMAIL

Byron Tapley
University of Texas, Austin
Center for Space Research
Building WRW, Room 402D
Austin, TX 78712-1085
Telemail: B.TAPLEY/OMNET

Larry D. Travis
Goddard Institute for Space Studies
National Aeronautics and Space Administration
2880 Broadway
New York, NY 10025
Telemail: LTRAVIS/NASAMAIL

Joe W. Waters
Jet Propulsion Laboratory
Mail Stop 183-701
Earth and Space Sciences Div.
4800 Oak Grove Drive
Pasadena, CA 91109
Telemail: JWATERS/J.P.L.

Bruce A. Wielicki
Langley Research Center
Mail Stop 420
National Aeronautics and Space Administration
Hampton, VA 23665-5225
Telemail: BAWIELICKI/NASAMAIL

Richard C. Willson
Jet Propulsion Laboratory
Mail Stop 171-400
4800 Oak Grove Drive
Pasadena, CA 91109
Telemail: ACRIM

EOS Acronyms & Abbreviations

2-D	Two-Dimensional
3-D	Three-Dimensional
4-D	Four-Dimensional
AAOE	Airborne Antarctic Ozone Experiment
AATSR	Advanced Along-Track Scanning Radiometer
ABLE	Atmospheric Boundary Layer Experiment
ACR	Active Cavity Radiometer
ACRIM	Active Cavity Radiometer Irradiance Monitor
ADALT'	Advanced Radar Altimeter
ADC	Affiliated Data Center
ADEOS	Advanced Earth Observing System
AE	Atmosphere Explorer
AER	Atmospheric and Environmental Research
AES	Atmospheric Environment Service
AGU	American Geophysical Union
AIAA	American Institute of Aeronautics and Astronautics
AIRS	Atmospheric Infrared Sounder
AIS	Airborne Imaging Spectrometer
ALT	Altimeter
AMS	American Meteorological Society
AMSR	Advanced Microwave Scanning Radiometer
AMSU-A	Advanced Microwave Sounding Unit-A
AMTS	Advanced Moisture and Temperature Sounder
AO	Announcement of Opportunity
APAFO	Advanced Particles and Fields Observer
APT	Automatic Picture Transmission
ARGOS+	Argos Data Collection and Position Location System
ARISTOTELES	Applications and Research Involving Space Technologies Observing the Earth's Field from Low Earth Orbiting Satellite
A-SAR	Advanced Synthetic Aperture Radar
A-SCAT	Advanced Scatterometer
ASF	Alaska SAR Facility
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATLAS	Atmospheric Laboratory for Applications and Science
ATMOS	Atmospheric Trace Molecules Observed by Spectroscopy
ATS	Advanced Technology Satellite
AURIO	Auroral Imaging Observatory
AVHRR	Advanced Very High-Resolution Radiometer
AVIRIS	Airborne Visible Infrared Imaging Spectrometer
AVNIR	Advanced Visible and Near-Infrared Radiometer
C	Centigrade
CCD	Charged Coupled Device
CCRS	Canada Centre for Remote Sensing
CDOS	Customer Data and Operations System
CEES	Committee on Earth and Environmental Sciences
CEOS	Committee on Earth Observations Satellites
CERES	Clouds and Earth's Radiant Energy System
CIESIN	Consortium for International Earth Science Information Networks
CIT	California Institute of Technology
CLAES	Cryogenic Limb Array Etalon Spectrometer
CNES	Centre National d'Etudes Spatiales
CNRS	Centre National de la Recherche Scientifique
cm	centimeter
CODMAC	Committee on Data Management, Archiving, and Computing

COSPAR	Congress for Space Research
CRYSYS	Cryospheric System
CSA	Canadian Space Agency
CSIRO	Commonwealth Scientific and Industrial Research Organization
CZCS	Coastal Zone Color Scanner
DAAC	Distributed Active Archive Center
DADS	Data Archive and Distribution System
DE	Dynamics Explorer
DEM	Digital Elevation Model
DIAL	Differential Absorption Lidar
DIS	Data Information System
DLS	Dynamics Limb Sounder
DMSP	Defense Meteorological Satellite Program
DoD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DRS	Data Relay Satellite
DSB	Direct Sounding Broadcast
DWS	Doppler Wind Sensor
EDC	EROS Data Center
E-LIDAR	Experimental Lidar
ENSO	El Niño Southern Oscillation
EOC	EOS Operations Center
EO-ICWG	Earth Observations International Coordination Working Group
EOPM	Electro-Optic Phase Modulation
EOS	Earth Observing System
EOSDIS	EOS Data and Information System
EOSP	Earth Observing Scanning Polarimeter
EPA	Environmental Protection Agency
EPOP	European Polar-Orbiting Platform
ERBE	Earth Radiation Budget Experiment
ERL	Environmental Research Laboratory
EROS	Earth Resources Observation System
ERS-1	European Remote Sensing Satellite-1
ERTS-1	Earth Resources Technology Satellite-1
ESA	European Space Agency
ESAD	Earth Science and Applications Division
ESMR	Electronically Scanned Microwave Radiometer
ESSC	Earth System Sciences Committee
EUMETSAT	European Meteorological Satellites Organization
EUV	Extreme Ultraviolet
FCCSET	Federal Coordinating Council for Science, Engineering, and Technology
FIFE	First ISLSCP Field Experiment
FIRE	First ISCCP Regional Experiment
FOT	Flight Operations Team
FOV	Field-of-View
FRG	Federal Republic of Germany
FST	Field Support Terminal
FY	Fiscal Year
GAC	Global Area Coverage
GCC	Global Change Category
GCRP	Global Change Research Program
Geosat	Navy Geodetic Satellite
GEWEX	Global Energy and Water Cycle Experiment

GGI	GPS Geoscience Instrument
GGS	Global Geospace Science
GHz	Gigahertz
GISS	Goddard Institute for Space Studies
GLI	Global Imager
GLL	Galileo
GLRS	Geoscience Laser Ranging System
GOMOS	Global Ozone Monitoring by Occultation of Stars
GOMR	Global Ozone Monitoring Radiometer
GOS	Geomagnetic Observing System
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
HALOE	Halogen Occultation Experiment
HIRDLS	High-Resolution Dynamics Limb Sounder
HIRIS	High-Resolution Imaging Spectrometer
HIRS	High-Resolution Infrared Sounder
HIS	High-Resolution Interferometer Sounder
HMMR	High-Resolution Multifrequency Microwave Radiometer
HRPT	High-Resolution Picture Transmission
Hz	Hertz
IAU	International Astronomical Union
ICC	Instrument Control Center
ICE	International Cometary Explorer
ICF	Instrument Control Facility
ICSU	International Council of Scientific Unions
IEEE	Institute for Electronics and Electrical Engineering
IEOS	International Earth Observing System
IFOV	Instantaneous Field-of-View
IGBP	International Geosphere-Biosphere Program
ILAS	Improved Limb Atmospheric Spectrometer
IMB'	Investigator of Micro-Biosphere
IMG	Interferometric Monitor
IMS	Information Management System
in	inch
IOC	Intergovernmental Oceanographic Commission
IPEI	Ionospheric Plasma and Electrodynamics Instrument
IPOC	International Partner Operations Center
IR	Infrared
IRIS	Incorporated Research Institutions of Seismology
ISAMS	Improved Stratospheric and Mesospheric Sounder
ISCCP	International Satellite Cloud Climatology Project
ISEE	International Sun-Earth Explorer
ISLSCP	International Satellite Land Surface Climatology Project
IST	Instrument Support Terminal
ISTP	International Solar Terrestrial Physics
ITIR	Intermediate Thermal Infrared Radiometer
IWG	Investigator Working Group
IWGDMGC	Interagency Working Group on Data Management for Global Change
JEOS	Japanese Earth Observing System
JEM	Japanese Experiment Module
JGOFS	Joint Global Ocean Flux Study
JMA	Japan Meteorological Association
JPL	Jet Propulsion Laboratory
JPOP	Japanese Polar-Orbiting Platform

JSC	Johnson Space Flight Center
K	Kelvin
kbps	kilobits per second
keV	kilo electron Volts
kg	kilogram
km	kilometer
kW	kilowatt
LAC	Local Area Coverage
LAGEOS	Laser Geodynamics Satellite
Landsat	Land Remote Sensing Satellite
LAWS	Laser Atmospheric Wind Sounder
LEFI	Local Electric Field Instrument
LERTS	Laboratoire d'Etudes et de Recherches en Teledetection Spatiale
Lidar	Light Detection and Ranging
LIDQA	Landsat Image Data Quality and Analysis
LIMS	Limb Infrared Monitor of the Stratosphere
LIS	Lightning Imaging Sensor
LRPT	Low-Resolution Picture Transmission
m	meter
Magsat	Magnetic Field Satellite
MAHLOVS	Middle and High Latitudes Oceanic Variability Study
Mbps	Megabits per second
MCP	Meteorological Communications Package
MEPED	Medium-Energy Proton and Electron Detector
MERIS	Medium-Resolution Imaging Spectrometer
MESSR	Multispectral Electronic Self-Scanning Radiometer
METEOSAT	Meteorology Satellite
MeV	Mega electron Volts
MFE	Magnetic Field Explorer
MHS	Microwave Humidity Sounder
MIMR	Multifrequency Imaging Microwave Radiometer
min	minute
MIPAS	Michelson Interferometric Passive Atmosphere Sounder
MISR	Multi-Angle Imaging Spectro-Radiometer
MIT	Massachusetts Institute of Technology
MITI	Ministry of International Trade and Industry
MLS	Microwave Limb Sounder
mm	millimeter
MODIS-N	Moderate-Resolution Imaging Spectrometer-Nadir
MODIS-T	Moderate-Resolution Imaging Spectrometer-Tilt
MOPITT	Measurements of Pollution in the Troposphere
MOS-1	Marine Observation Satellite-1
MSU	Microwave Sounding Unit
n/a	Not Applicable
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications Network
NASDA	National Space Development Agency of Japan
NBIOME	Northern Biosphere Observation and Modeling Experiment
NBIS	Northern Biosphere Information System
NCAR	National Center for Atmospheric Research
NERC	National Environmental Research Centre
NESDIS	National Environmental Satellite, Data, and Information Service
nm	nanometer

NMC	National Meteorology Center
NOAA	National Oceanic and Atmospheric Administration
NODS	NASA Ocean Data System
NRC	National Research Council
NRL	Naval Research Laboratory
NSCAT	NASA Scatterometer
NSF	National Science Foundation
NWP	Numerical Weather Prediction
NWS	National Weather Service
OCTS	Ocean Color and Temperature Scanner
OSSA	Office of Space Science and Applications
OSTP	Office of Science and Technology Policy
PGS	Product Generation System
PI	Principal Investigator
PMC	Pressure-Modulated Cell
PMIR	Pressure Modulator Infrared Radiometer
PMR	Pressure-Modulated Radiometer
POEM	Polar-Orbit Earth observation Mission
POES	Polar-Orbiting Environmental Satellites
POGO	Polar-Orbiting Geophysical Observatory
POLDER	Polarization and Directionality of Reflectances
POLES	Polar Exchange at the Sea Surface
ppm	parts per million
PPR	Photopolarimeter Radiometer
PR	Precipitation Radar
PRAREE	Precise Range and Rate Equipment—Extended Version
PRF	Pulse Repetition Frequency
QC	Quality Control
RA	Radar Altimeter
RIS	Retroreflector In Space
rpm	revolutions per minute
rss	root sum square
S&R	Search and Rescue
SAFIRE	Spectroscopy of the Atmosphere using Far Infrared Emission
SAGE	Stratospheric Aerosol Gas Experiment
SAM	Stratospheric Aerosol Measurement
SAMS	Stratospheric and Mesospheric Sounder
SAR	Synthetic Aperture Radar
SARSAT	Search and Rescue
SBUV	Solar Backscatter Ultraviolet
SCF	Science Computing Facility
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
Seasat	Sea Satellite
sec	second
SEC	Science Executive Committee
SEM	Space Environment Monitor
SI	Solar Influences
SIR	Spaceborne Imaging Radar
SIR-C	Shuttle Imaging Radar-C
SISEX	Shuttle Imaging Spectrometer Experiment
SLIES	Stratospheric Limb Infrared Emission Spectrometer
SMC	System Management Center
SME	Solar-Mesosphere Explorer
SMMR	Scanning Multispectral Microwave Radiometer

SNR	Signal-to-Noise Ratio
SOLSTICE	Solar Stellar Irradiance Comparison Experiment
SPIE	Society of Photo-Optical Instrumentation Engineers
SPOT	Systeme pour l'Observation de la Terre
SSM/I	Special Sensor Microwave/Imager
STA	Science and Technology Agency
STIKSCAT	Stick Scatterometer
SWIR	Short Wavelength Infrared
SWIRLS	Stratospheric Wind Infrared Limb Sounder
TBD	To Be Determined
TDRSS	Tracking and Data Relay Satellite System
TED	Total Energy Detector
TERSE	Tunable Etalon Remote Sounder of Earth
TES	Tropospheric Emission Spectrometer
TGT	TDRSS Ground Terminal
TIR	Thermal Infrared
TIROS	Television Infrared Observing Satellite
TM	Thematic Mapper
TOGA	Tropical Ocean Global Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TOMUIS	3-D Ozone Mapping with Ultraviolet Imaging Spectrometer
TOPEX	Ocean Topography Experiment
TOVS	TIROS Operational Vertical Sounder
TRMM	Tropical Rainfall Measuring Mission
U.S.	United States
UARS	Upper Atmosphere Research Satellite
UCLA	University of California, Los Angeles
UCSB	University of California, Santa Barbara
UHF	Ultra High Frequency
UK	United Kingdom
UNEP	United Nations Environment Program
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
UV	Ultraviolet
VIS	Visible
VHF	Very High Frequency
VNIR	Visible and Near -Infrared
W	Watt
WBDCS	Wide-Band Data Collection System
WCRP	World Climate Research Program
WHOI	Woods Hole Oceanographic Institution
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
X-SAR	X Band Synthetic Aperture Radar
XIE	X-ray Imaging Experiment

DO NOT REMOVE SLIP FROM MATERIAL

Delete your name from this slip when returning material to the library.

NAME	DATE	MS
[redacted]		

NASA Langley (Rev. Dec. 1991) RIAD N-75

NP-144