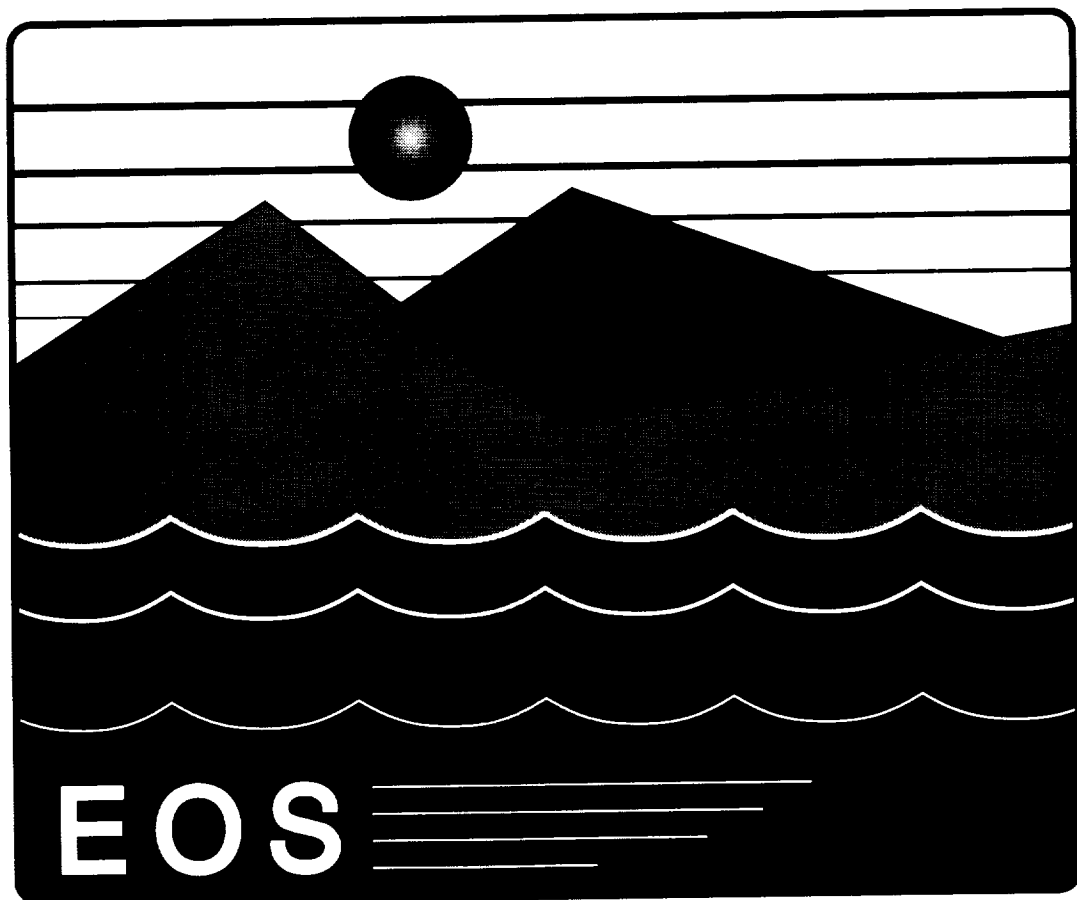


1990 REFERENCE HANDBOOK

Goddard Space Flight Center

NASA



Earth Observing System

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THE EARTH OBSERVING SYSTEM

AN OVERVIEW

Developing a comprehensive understanding of how the Earth functions requires global observations on a sustained, consistent basis for a decade or longer. 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*.

The Earth Observing System (EOS) has been conceived and designed to provide observations from satellites in low-altitude Earth orbit. 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 capability will build up over 10 years, then function for at least a decade at its full capacity to allow accurate modeling of the processes that control the environment.

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 Space Measurement System (EOSSMS).

The foundation of EOS is its scientific research. This effort is already underway, building on and

complementing the Earth science research efforts of the National Aeronautics and Space Administration (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. Global Change Research Program (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 EOSSMS and the EOSDIS. Through an EOS graduate fellowship program and the involvement of graduate and post-doctoral students in EOS research, provision will be made for growth in the number of Earth scientists ready to use EOS data.

A fundamental goal of the EOS program is to facilitate both 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;

THE EARTH OBSERVING SYSTEM

processing, distribution, and archiving of EOS data; and command and control of the EOSSMS.

The EOSSMS development effort will begin with formal approval of the EOS program. 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 EOSSMS. 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 EOSSMS processing, distribution, and archiving activities will be put in place for testing by the research community. Before launch, the full scope of EOSSMS will be made available for use in testing the EOSSMS and instrument algorithms, as well as for enhanced support of ongoing EOS research. After launch, EOSSMS will continue to evolve and grow in capability in response to lessons learned through its use. This continuing evolution will permit exploitation of advances in data system technologies.

In parallel with EOSSMS development, the EOS Space Measurement System will be realized. The capabilities of the EOSSMS are determined by the individual instruments and the manner in which they are deployed 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.

EOSSMS 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 (ESA), 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. Each platform-payload combination will be replaced at 5-year intervals to provide for 15 years of continuous data. Thus, NASA's EOS mission obligation entails six platforms and three copies of each selected instrument. 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 Global Change Research Program is an integrated effort of seven U.S. Government agencies:

- National Aeronautics and Space Administration (NASA)
- National Science Foundation (NSF)
- 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).

This effort is organized under the auspices of the Committee on Earth Sciences (CES), 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 and, hence, establish the scientific basis for national and international policy formulation and decisions relating to natural and human-induced changes in the global environment and their regional impacts.

The current overall research program is described in *Our Changing Planet: The FY 1990 Research Plan*. This document includes identification of the key scientific questions, the priorities among research needs, and identification of specific agency roles. The plan for the GCRP identifies three science objectives which serve as the integrating priorities for the program. These are:

- 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.

The overall scientific research effort has been divided into seven science areas as shown in Figure 1. Topics within each area have been listed in priority order. There is also a general sense that priority decreases as one moves from left to right across this figure, although all of the research topics listed are required for the success of the comprehensive effort to understand the total Earth system.

NASA's Earth Science and Applications program, virtually all of which is focused on the study of global change, contributes to research efforts in five of the seven areas highlighted in Figure 1.

EOS will be NASA's major contribution to the GCRP, serving as the cornerstone of a long-term program to document global change. The EOSSMS will make up most of the space segment of the GCRP observational program, with the EOSDIS providing the framework for a global change data management system. The 28 interdisciplinary investigations that comprise a major portion of EOS science program will make significant contributions to the understanding of Earth system processes and to the development of Earth system models.

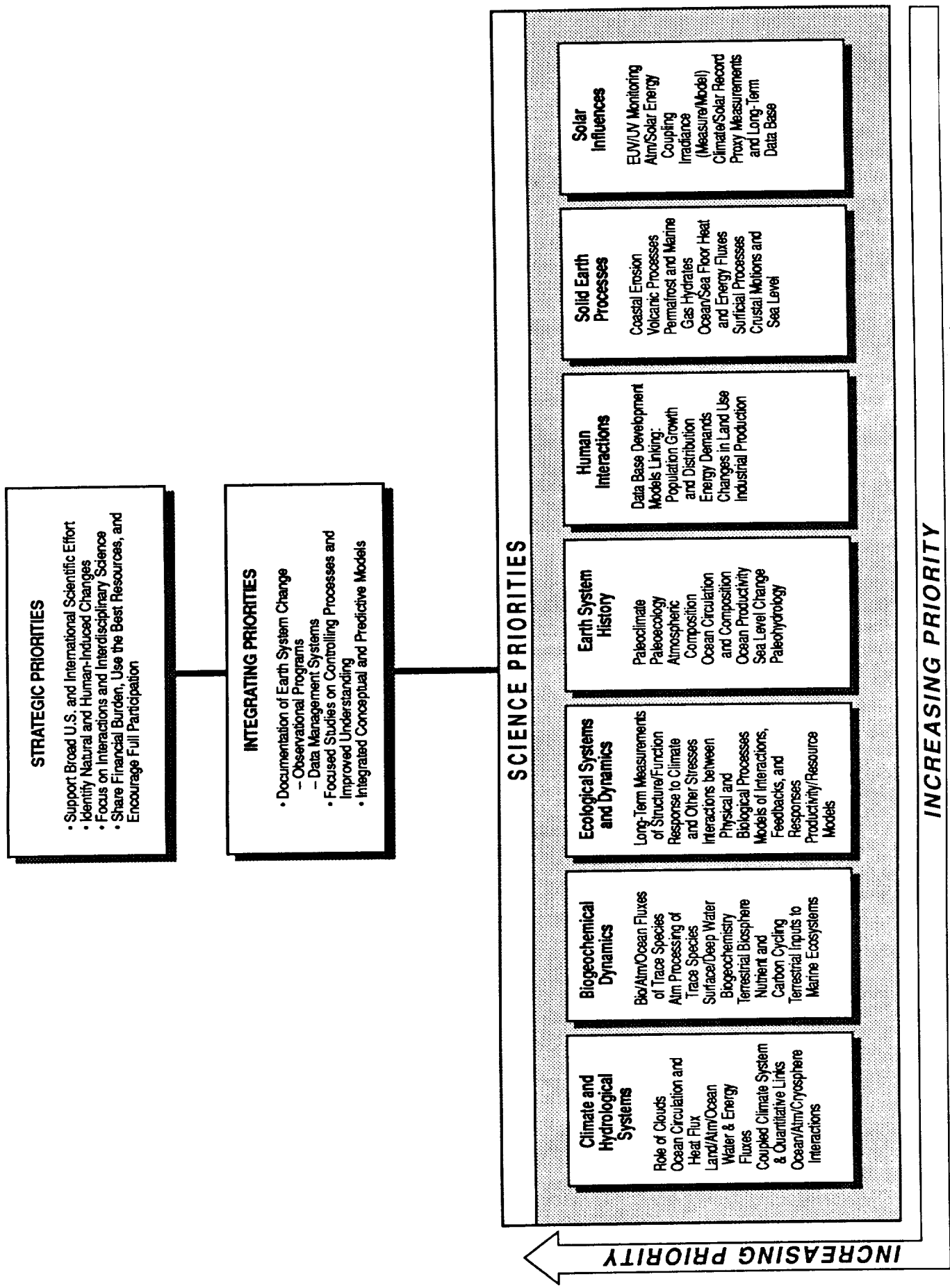


Figure 1. Overall EOS Research Priorities

INTERNATIONAL COORDINATION MECHANISMS

The nature of the Global Change Research Program requires extensive international cooperation. Existing coordination mechanisms are being used wherever possible, with new ones created only when necessary. The two key coordinating efforts involve the ongoing World Climate Research Program and the nascent International Geosphere-Biosphere Program. Both exist under the auspices of the International Council of Scientific Unions (ICSU), with WCRP being accomplished in partnership with the World Meteorological Organization (WMO).

The informal planning that normally takes place in the international scientific community has evolved into large-scale international programs in support of global change research. ICSU efforts provide for the broadest possible involvement of the international research community in the study of global change, with the U.S. National Academy of Sciences (NAS) serving as the primary liaison to ICSU for the U.S. GCRP. The work of the NAS with respect to the IGBP is focused in its Global Change Committee, which is charged with reviewing the GCRP and with presenting the overall U.S. plans to the

international community. Figure 2 offers a schematic of the international programs and their interrelationships.

The three major intergovernmental science bodies essential to the implementation of the international study of global change are the WMO; the United Nations Educational, Scientific, and Cultural Organization (UNESCO) and its subsidiary bodies; and the United Nations Environment Program (UNEP). Under WMO, the WCRP contributes many key components to the global change research effort, including specialized programs such as the World Ocean Circulation Experiment (WOCE), the Tropical Ocean Global Atmosphere (TOGA) program, and the upcoming Global Energy and Water Cycle Experiment (GEWEX). Within UNEP, the Global Environmental Monitoring System (GEMS), the Global Resource Information Data Base (GRID), and other programs are important additions. The Man and the Biosphere (MAB) program and other UNESCO efforts are also contributing elements to the overall global change effort. In addition, there are numerous bilateral agreements in place and in process addressing many aspects of global change cooperation.

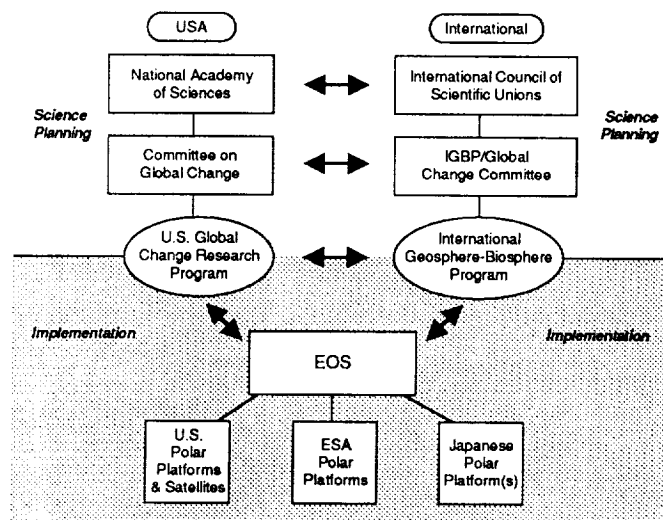


Figure 2. The Role of EOS in the U.S. Global Change Research Program and the International Geosphere-Biosphere Program

EOS GOAL AND OBJECTIVES

The goal of the EOS science mission is to advance the understanding of the entire Earth system on the global scale through developing a deeper understanding of the components of that system, the interactions among them, and how the Earth system is changing.

The EOS mission will create an integrated scientific observing system that will enable multidisciplinary study of the Earth, including the atmosphere, oceans, land surface, polar regions, and solid Earth. In order to quantify changes in the Earth system, Eos will be a long-term mission providing systematic, continuing observations from low Earth orbit.

More specific mission objectives are:

- 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 data base for remote sensing measurements from space over a decade or more to enable definitive and conclusive studies of Earth system science attributes
 - 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 observing capability (15 years)
- Maintain continuity in essential global change measurements of existing and planned missions (e.g., UARS, TOPEX/Poseidon)
- Obtain at least 1 decade of overlapping, calibrated data from the full EOS space measurement system (two NASA polar platforms, two ESA polar platforms, one Japanese polar platform)
- Globally characterize the highly variable aspects of the Earth system every 1 to 3 days
- For instruments having the potential to fly on multiple spacecraft, use instrument interfaces that are compatible with the ESA polar platforms and future NOAA polar orbiting operational satellites
- Make all EOS data readily available in a timely manner
- Support the communication and exchange of research findings that result from use of EOS data or are produced by EOS investigations
- Support the overall U.S. Global Change Research Program

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. All investigations were selected by NASA through a competitive process based on peer evaluation of scientific and technical merit of proposals solicited from the worldwide research community. The goal and objectives of the EOS mission as stated herein are the same as those upon which solicitation of scientific participation were based.

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:

- EOSDIS Advisory
- Payloads Advisory
- Calibration/Validation
- Precision Orbit Determination/Mission Design
- Physical Climate/Hydrology
- Biogeochemical Cycles
- Modeling
- Atmospheres
- Oceans
- Land/Biosphere
- Solid Earth
- Facility Instruments
- PI Instrument
- Particles and Fields.

Each panel is chaired by a member of the IWG, and these chairmen serve as the Science Executive Committee of the IWG. Membership on the panels is generally open to all EOS Investigators, including Co-Investigators on any EOS investigation, and members of EOS facility instrument teams. The only restrictions on membership to date have been the result of potential or actual conflicts of interest. Scientists outside the group of EOS investigators can and will be included in the various panels. Outside representation is required on the EOSDIS Advisory Panel.

EOS DATA AND INFORMATION SYSTEM ARCHITECTURE

The key functional objectives of EOSDIS are to provide:

- Command and control of NASA polar platforms
- EOS instrument command and control
- Processing and reprocessing of EOS data
- Data access and distribution
- Networking capabilities
- Transfer of data to permanent archives
- Exchange of data, commands, algorithms, etc., with NOAA, ESA, Japan, Canada, and possibly others.

EOSDIS Architecture (Preliminary Design)

The current plan for the EOSDIS architecture is illustrated in Figure 3. The design of EOSDIS is still evolving, and this architecture may be modified over the coming year or so. The overall design of EOSDIS is being studied by two industrial teams, with the EOSDIS Science Advisory Panel actively involved in all aspects of these studies. 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 EOSDIS must be secure and highly reliable.

EOSDIS Components

The EOSDIS architecture is composed of many types of elements, most of which will be redun-

dant and geographically distributed. The following paragraphs describe each individually.

The EOS Mission Operations Center (EMOC) 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 EMOC, which coordinates with external (i.e., non-EOS) systems such as the Customer Data and Operations System (CDOS) Platform Support Center (PSC), which in turn connects EOS with the Tracking and Data Relay Satellite System (TDRSS). The Payload Operations Integration Center (POIC) and the international Missions Operations Center (MOC) perform functions similar to those of the EMOC/PSC for the EOS attached payloads on the Space Station *Freedom* and the International Partner platforms.

The Customer Data and Operations System (CDOS) serves as NASA's ground-based interface between many different Earth-orbiting satellites and the TDRSS. It provides for the integration of command uplinks via the PSC and the segregation of data downlinks into separate mission data streams that have been corrected for artifacts of the telemetry process (level 0 processing, see page 14 for level definitions).

The Tracking and Data Relay Satellite System (TDRSS) relays data to and from low-altitude, Earth-orbiting satellites, the Space Shuttle, etc. 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 Center (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. Remote Instrument Control Centers (RICCs) are distributed subelements of the ICC.

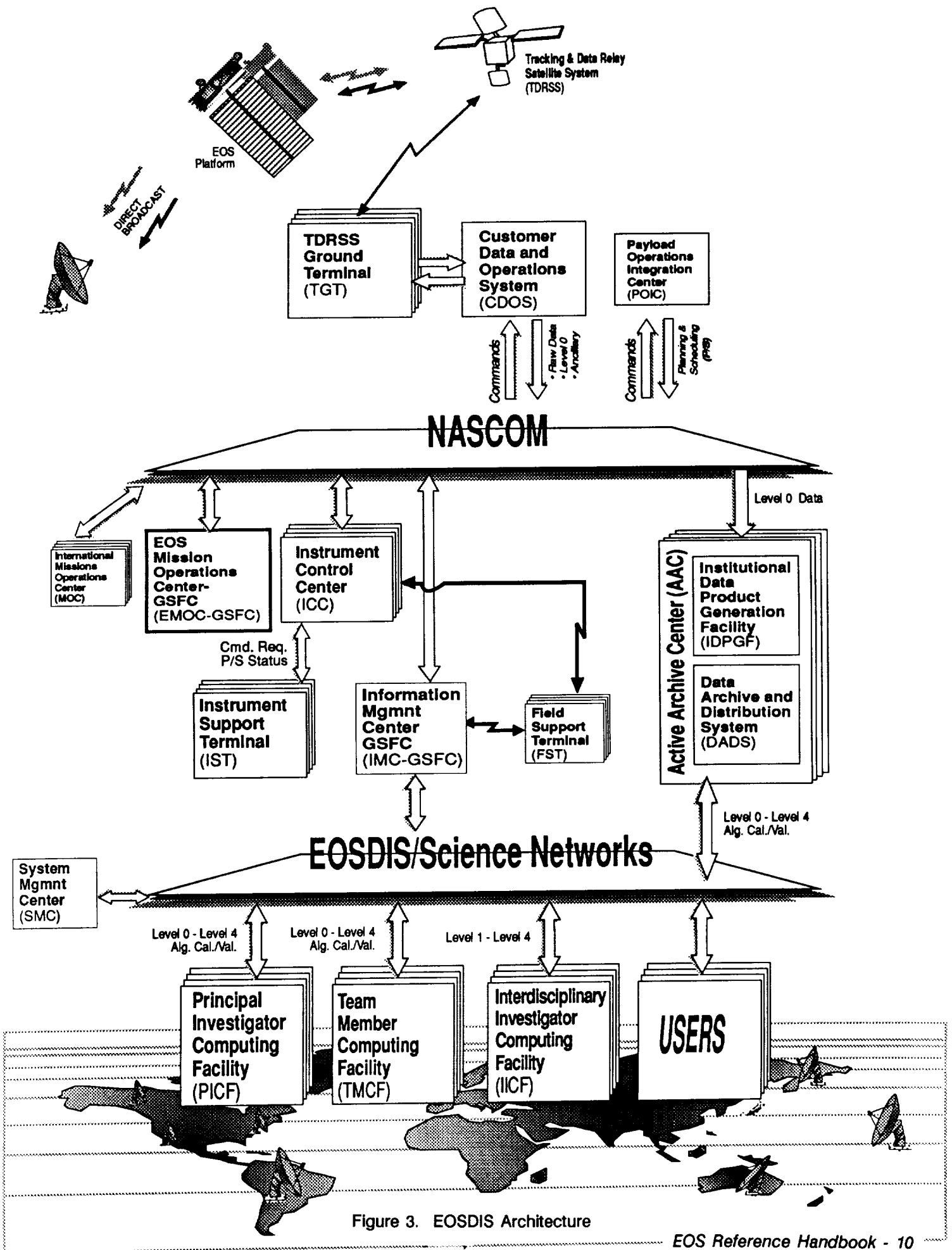


Figure 3. EOSDIS Architecture

EOS DATA AND INFORMATION SYSTEM ARCHITECTURE

The Instrument Support Terminals (ISTs) reside at Instrument Principal Investigator and Team Leader sites, providing information on the health and safety of individual instruments and enabling PIs and their engineering support teams to participate with instrument and mission controllers in the diagnosis and resolution of performance anomalies.

Institutional Data Product Generation Facilities (IDPGFs) perform data processing functions, including routine production 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.

A Data Archive and Distribution System (DADS) is responsible for archiving and distribution of EOS data and information. This includes level 0 and higher level data and products, ancillary and correlative data, metadata, command histories, algorithms, documentation, procedures for requesting special observations from EOS, simulation tools for planning and understanding observational sequences, and system management data. 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. DADS will be co-located with each IDPGF.

An Active Archive Center (AAC) 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 the responsibility of an investigator team. An EOS AAC [also called a Remote Active Archive Center (RAAC)] contains functional elements that normally include either or both an IDPGF for processing data and a DADS for archiving and disseminating data. 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.

A Permanent Archive is a facility funded independent of the EOS budget that may take responsibility for the permanent archiving 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 such. 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 NASA/National Space Science Data Center (NSSDC), the USGS/Earth Resources Observation System (EROS) data center, and the NOAA/National Environmental Satellite, Data, and Information Service (NESDIS) data centers.

The Information Management Center (IMC) is the user interface for EOSDIS. It 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.

The Scientific Computing Facilities (SCFs) involve those capabilities provided by the EOS program to scientists at Team Member, PI, and Instrument Investigator Computing Facilities (TMCF, PICF, and IICF) for development and maintenance of algorithms/software for generation of standard data products, quality control of products, data set validation, in-flight calibration, scientific analysis, modeling, research, generation of specialized data products, instrument operations planning, and interface to scientists' institutional facilities.

Networks are electronic means for distributing EOS data and information to all nodes within the

EOS DATA AND INFORMATION SYSTEM ARCHITECTURE

system and to the scientific research community at large, including 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 field campaigns to coordinate platform data acquisition with field experiments and to yield the necessary display capabilities to support field experiment needs.

EOS Investigators will be able to access all mission planning and scheduling information via the IMC, using their SCFs as remote interfaces. Requests for future data from instruments that require advanced scheduling will be placed through the IMC, 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 through the IWG), who will communicate electronically with the ICC through their SCFs in order for the ICC staff to prepare the command streams that will be transmitted to the EMOC and thence to the instruments on the spacecraft.

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 active archives for further processing and distribution. The IMC 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 IMC. They will also be able to request all supporting algorithms, models, documentation, etc., through the IMC. 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 instrument performance will be routed directly to the EMOC and ICCs, where 24-hour monitoring of the 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.

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

- Algorithms (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 scientific computing facilities
- Deliver specialized products and algorithms to be archived
- Provide ongoing scientific quality control for standard products

EOS DATA AND INFORMATION SYSTEM ARCHITECTURE

- 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 investigations. 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. An EOSDIS standards office 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. EOSDIS will therefore 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 active archives. Starting now, EOSDIS design and development 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 System Management function, along with the EOS Mission Operations Center and the

primary Information Management Center, will be located at Goddard Space Flight Center (GSFC). ICCs will be located at GSFC, the Jet Propulsion Laboratory (JPL), and possibly other sites. As indicated, the IDPGF and DADS functions will be co-located to form Active Archive Centers, and distributed 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 AAC activities (e.g., NASA/NSSDC, NOAA, and USGS). The proposed distribution of AACs follows:

- Upper Atmosphere, Meteorology, Ocean Color GSFC
(Experience with UARS, atmospheric sounding and tropospheric moisture sensing, and CZCS and AVHRR)
- Physical Oceanography, Air-Sea Interaction JPL
(Experience with Seasat, TOPEX, NSCAT, SSM/I, NODS)
- Radiation Budget, Upper Atmosphere Langley Research Center
(Experience with ERBE, SAGE)
- Snow and Ice (non-SAR) National Snow and Ice Data Center
(Experience with SMMR, SSM/I)
- Land Processes Imagery EROS Data Center/USGS
(Experience with Landsat, AVHRR)
- Sea Ice (SAR) University of Alaska - Fairbanks
(Experience with Alaska SAR Facility).

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

EOS DATA AND INFORMATION SYSTEM ARCHITECTURE

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 EOS IDPGFs.

Specialized 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 specialized data products. Specialized data products will normally be generated at investigator SCFs (provided for EOS investigators out of the EOS budget). Specialized 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 IDPGFs 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 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 (e.g., radar backscatter cross section, brightness temperature). Not all instruments will have a level 1B equivalent.

Level 2 - Derived environmental variables (e.g., ocean wave height, soil moisture, ice concentration) 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 (e.g., missing points interpolated, complete regions mosaicked together from multiple orbits).

Level 4 - Model output or results from analyses of lower level data (i.e., variables that are not measured by the instruments, but are derived from these 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. To this end:

- Data from EOS instruments will be acquired according to priorities recommended by the IWG and the International Coordination Working Group (ICWG) and confirmed by NASA Headquarters.
- Where EOS sensors make site-specific observations, EOS will be an "acquire-on-demand" system. That is, data will only be taken in cases where there is an identified user who has requested the data and will analyze it.
- 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 can 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 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 produced 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 agency users (e.g., NOAA, EUMETSAT), and others (primarily commercial users). Different arrangements are foreseen depending on the type of user.

Research Users. Research users are those who agree to pay the nominal incremental cost to the EOS project of reproducing and delivering the data requested, and who sign a "research agreement" stating that: (1) they will publish in the open literature results of research based in whole or in part on data obtained from EOS; (2) they will make available to the research community their detailed results, including data, algorithms, and models at the time their research is accepted for publication; (3) the data are for the researcher's use for bona fide research purposes only; and (4) the data may be copied and shared among other researchers provided that either they are covered by a research agreement or the researcher who obtained the

DATA POLICY

data from EOSDIS is willing to take responsibility for their compliance with the agreement.

It is anticipated that a researcher or research group will sign one research agreement when establishing their account on EOSDIS and that this will serve indefinitely to fulfill this requirement. 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 have access to all EOS data at the incremental cost of reproduction and delivery. 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. 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 U.S. researchers who sign the research agreement will also have access to all EOS data at the incremental cost of reproduction and delivery. The same conditions apply to them as to EOS investigators.

Research users affiliated with EOS-participating countries (at present this includes ESA member states, Japan, and Canada) will have the same access as researchers described above. It is NASA's intent to make its EOS data available on this basis to researchers in any other country that is openly sharing its Earth science data and

actively contributing to the international efforts that parallel the U.S. Global Change Research Program (e.g., IGBP and WCRP). If the research contributions of another country are recognized by the ICWG as constituting participation, these same privileges will extend to all polar platform data without the need to reach specific agreements with each partner. NASA is negotiating agreements with its international polar platform partners to obtain foreign data for U.S. researchers on the same basis that EOS data are made available to foreign researchers. Users from non-participating countries, whether researchers or not, will have access to all EOS data, but on the commercial terms described below.

Operational Agency Users. Operational agencies (e.g., NOAA, EUMETSAT) may obtain real-time access to data from instruments of interest (NOAA operational payload on ESA EPOP- M1 and NOAA free-flyers, plus NASA EOS research sensors designated as having operational potential) through their own direct readout facilities and/or via data relay satellites. Near-real-time distribution for operational purposes will be handled by NOAA for its user community. NOAA will perform its own data processing and will maintain its own archive for these data. Non-real-time access to EOS research data by operational agencies will be provided by NASA at the incremental cost of reproduction and delivery, and will be subject to the terms of the research agreement.

Other (Primarily Commercial) Users. NASA will develop a procedure, consistent with the Land Remote Sensing Commercialization Act or other applicable statutes, for commercial distribution on a non-discriminatory basis to non-research/non-operational users.

EOS SPACE MEASUREMENT SYSTEM

In order to meet the measurement goals of the EOS science program, the EOSSMS will consist of two series of polar platforms (EOS-A series and EOS-B series) with complementary payloads, launched on Titan IV Expendable Launch Vehicles (ELVs). Each platform will be replaced every 5 years to achieve the 15-year mission lifetime goal. On-orbit servicing was considered, but studies concluded that the technical risks were substantially higher than replacement, with no significant cost savings. However, the platforms are designed so as not to preclude servicing should the technology become available. As such, 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 call for the EOS-A and EOS-B series to be joined by a dedicated EOS SAR platform in 1999. The observational capabilities of the EOSSMS will also be supplemented by NOAA, European, and Japanese polar platforms 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. The final allocation of instruments and other payload elements to specific platforms will be in accordance with selection confirmation decisions to be made in September 1990 for EOS-A and roughly 1 year later for EOS-B.

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.

First, 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 of the EOS instruments observe dynamic phenomena that do change rapidly.

Second, 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, HIMSS, LIS, AIRS, and AMSU). 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 could be augmented with HIRIS and ITIR to provide finer spatial resolution measurements to examine sub-pixel variations within the measurements of these other sensors, but this is not the primary use of HIRIS and ITIR.

The second grouping includes the optical surface imagers (i.e., MODIS, HIRIS, ITIR, 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 ITIR 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.

EOS SPACE MEASUREMENT SYSTEM

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.

Third, 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, ITIR, HIMSS, 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.

Fourth, measurements produced by EOS 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 allows 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 (or SCANSCAT) is flown on the same platform as HIMSS or another scanning microwave radiometer that 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 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 pm 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

EOS SPACE MEASUREMENT SYSTEM

that are close to those of the primary NOAA polar operational mission.

The current proposed scenario is given in Figure 4. This configuration was agreed upon at the November 1989 meeting of the ICWG. The absence of detailed instrument

lists for the ESA EPOP-N1 and Japanese polar platforms indicates that the payloads for these platforms will be substantially affected by the final choice of instruments for the EOS-A and ESA EPOP-M1 payloads.

OBJECTIVES	ESA EPOP M-1 790 KM, 10:00 AM 1997	NASA EOS-A 705 KM 1:30 PM 4Q 1997	NOAA-O 824 KM 1:30 PM 1Q 1998	JPOP 4Q 1998	NASA ATI/PL 400 KM 1998	NASA EOS SAR 1:30 PM 659 KM 1999	NASA EOS-B 705 KM 1:30 PM 4Q 1999	ESA EPOP N-1 2000
VIS/IR IMAGERS	MERIS AMRIR POLDER	MODIS-N MODIS-T/MERIS HIRIS ITIR MISR, EOSP	AMRIR		LIS		LIS	
RADIATION BUDGET	CERES (1/2) POLDER AATSR	CERES			CERES			
ATMOS. SOUNDING	SCIAMACHY AMSU	AIRS AMSU	AMSU AMRIR					
PASSIVE MICROWAVE		HIMSS/MIMR/AMSR						
ACTIVE MICROWAVE	AMI-2					SAR		
TROPO. CHEMISTRY		HOPITT/TRACER					TES	
STRAT. CHEMISTRY	MIPAS SCIAMACHY DWS	HIRDLS	GOMR				SAFIRE MLS SWIRLS SAGE III	
WIND	AMI-2			LAWS			STIKSCAT/ SCANSCAT	
ALTIMETER	RA						ALTRAGLRS	
LASER RANGING							GLRS	
OPER. INSTR.	AMRIR AMSU SEM S&R		AMRIR AMSU GOMR SEM S&R					
OTHER	ARGOS COMM PKG	GGI WBDCS COMM PKG IPEI	ARGOS COMM PKG		ACRIM ON FLIGHT OF OPPORTUNITY		GGI COMM PKG IPEI, GOS, XIE SOLSTICE	

Figure 4. Proposed EOS Configuration Scenario

INTERNATIONAL COOPERATION

The U.S. Global Change Research Program is closely linked to a broader international global change research effort. These international research relationships are described in the *U.S. Global Change Research Program Plan, Our Changing Planet: The FY 1990 Research Plan*. Among these is the international cooperation between NASA and its partners in the EOS program.

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 a global polar-orbiting observing capability in the 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 the 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 contributions to EOS are expected.

Europe. ESA will provide two series of polar platforms along with instrumentation, launch, operations, and the associated data system. ESA may also contribute one or more instruments for flight on the NASA platforms. The research effort, the data exploitation aspects of the data system, and a number of the individual

instruments are national contributions from the individual member states of ESA. In addition, the UK has proposed the DLS portion of the HIRDLS instrument, which is a candidate for flight on EOS-A, and the UK and France are sponsoring EOS interdisciplinary investigations. ESA and EUMETSAT will coordinate the flight of a suite of operational instruments in a morning crossing time orbit. This payload, which will be provided through NOAA, will complement the observations provided by the continuing series of NOAA afternoon free-flying satellites. ESA will also fly at least one NASA instrument (i.e., CERES) on the first ESA platform.

Japan. Japan will provide at least one polar platform, which will fly NASA's LAWS and other instruments that have yet to be determined. In addition, Japan is providing the ITIR instrument for flight on EOS-A and may provide additional instruments. Japan is sponsoring an EOS interdisciplinary investigation.

Canada. The Canadian Space Agency has requested funding to provide the X-band direct downlink capability for the NASA polar platforms. In addition, Canada has proposed the MOPITT instrument, which is a candidate for flight on EOS-A; Canada is sponsoring two EOS interdisciplinary investigations.

Other. In addition to the countries above, EOS investigations were selected by NASA and are being funded by national agencies in Brazil, Australia, and the People's Republic of China.

ROLE OF NOAA

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 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 for real-time operational evaluation. NOAA will also serve as the long-term archivist for a portion of the oceanic and atmospheric data from EOS.

EOS FELLOWSHIP PROGRAM

The EOS program has included a specially earmarked fund in its budget plans to establish an Earth Science Fellowship Program. Starting with 25 fellowships to be awarded in 1990, the program will fund up to 150 graduate students per year for the duration of the mission. The EOS Fellowship Program will increase the number of Earth scientists in the EOS era and will attract participation in the EOS program by outstanding scientists and engineers. A national competition is planned to recommend and make awards for research support to graduate students enrolled in full-time Ph.D. programs at accredited U.S. universities.

Awards will be made for an initial 1-year term and may be renewed annually up to 3 years, based on satisfactory progress as reflected in academic performance and evaluations by the faculty advisor. The amount of award for 1990 is expected to be \$16,000 per annum, which may be used at the discretion of the student to defray living expenses, tuition, and fees. A further amount of \$2,000 will be available by

request for the faculty advisor's use in support of the student's research. Applications will be considered for research on global biogeochemical cycles, radiation and physical climate interactions, the hydrological cycle, and solid Earth processes. Atmospheric and ocean physics, chemistry and biology, ecosystem dynamics, soil science, geology, geophysics, and cryospheric processes are all acceptable areas of research, providing that the specific research topic is relevant to NASA's global change research efforts (the Earth Observing System and Mission to Planet Earth). Requests for more information should be directed to:

Global Change Fellowship Program
Code EPM-20
NASA Headquarters
Washington, DC 20546

The deadline for receipt of fellowship application materials is April 15, 1990, for the 1990/1991 academic year.

PLANS AND STATUS

1990	May-June	Instrument Execution Phase Conceptual Design and Cost Reviews
	May-July	Interdisciplinary Investigation Performance Reviews
	September	Final Selection of Instruments for EOS-A; Confirmation of All Other Definition-Phase Selections
	October	Start of Phase C/D for EOS Official Decision on Launch Date
1991	January	Initiation of Payload Execution Phase
1995	December	Delivery of Instruments to NASA for Integration on EOS-A
1997	April	Launch of ESA EPOP-M1 Polar Platform
	4th Qtr	Earliest Possible Launch of EOS-A
	December	Delivery of Instruments to NASA for Integration on EOS-B
1998	1st Qtr	Earliest Possible Launch of NOAA-O
	4th Qtr	Earliest Possible Launch of Japanese Polar Platform Earliest Possible Launch of NASA Attached Payloads
1999	1st Qtr	Earliest Possible Launch of EOS SAR
2000	2nd Qtr	Earliest Possible Launch of EOS-B Earliest Possible Launch of ESA EPOP-N1 Polar Platform

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 GSFC.

The program office for EOS within OSSA is the Earth Science and Applications Division, 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. This office has been reorganized to better accomplish the EOS mission. The key aspects of this structure are assignment of EOSSMS program management duties to an Associate Director, assignment of EOSDIS program management duties to the

Associate Director for Modeling and Data Analysis, and the provision of a dedicated, full-time EOS Program Scientist with a staff to coordinate mission science.

GSFC has also reorganized to better accomplish its EOS responsibilities. Key features of this 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 the 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.

MISSION ELEMENTS

EOS-A

Platform Science Objectives:

- Global Quantification of Hydrologic Cycle
 - Evaporation, precipitation, transport of water vapor
- Continued Monitoring of Radiation Budget/Surface Temperature
 - Follow-on to ERBE
- Comprehensive Study of Clouds
- Characterization of Biological Activity/Ecosystems
 - Optical measurements only
- Improved Study of Atmospheric Circulation
- Global Determination of Surface Mineralogy

Core Payload Candidates:

- Visible/Infrared Imagers: MODIS-N, MODIS-T/MERIS, HIRIS, ITIR, MISR, and EOSP
- Radiation Budget: CERES
- Atmospheric Sounding: AIRS, AMSU
- Passive Microwave: HIMSS/MIMR/AMSR
- Tropospheric Chemistry: MOPITT/TRACER
- Stratospheric Chemistry: HIRDLS

Other Instrument Candidates: GGI, WBDCS, Communication Package, IPEI.

Platform Design Capabilities: EOS-A has a 5-year design life, a payload mass of 3,000 to 3,500 kg, 6 kW average power for the platform itself and 3.2 kW for the payload, 300 Mbps peak data rate, 30 to 50 Mbps average data rate, and 0.5 terabyte of on-board data storage.

The present baseline calls for replacement of the platform after 5 years; however, the platform is designed to be serviceable if an effective means of on-orbit servicing becomes available during the life of the mission. Figure 5 provides a line drawing of EOS-A.

Orbit Choice: 705 km, sun-synchronous, 1:30 pm equatorial crossing time.

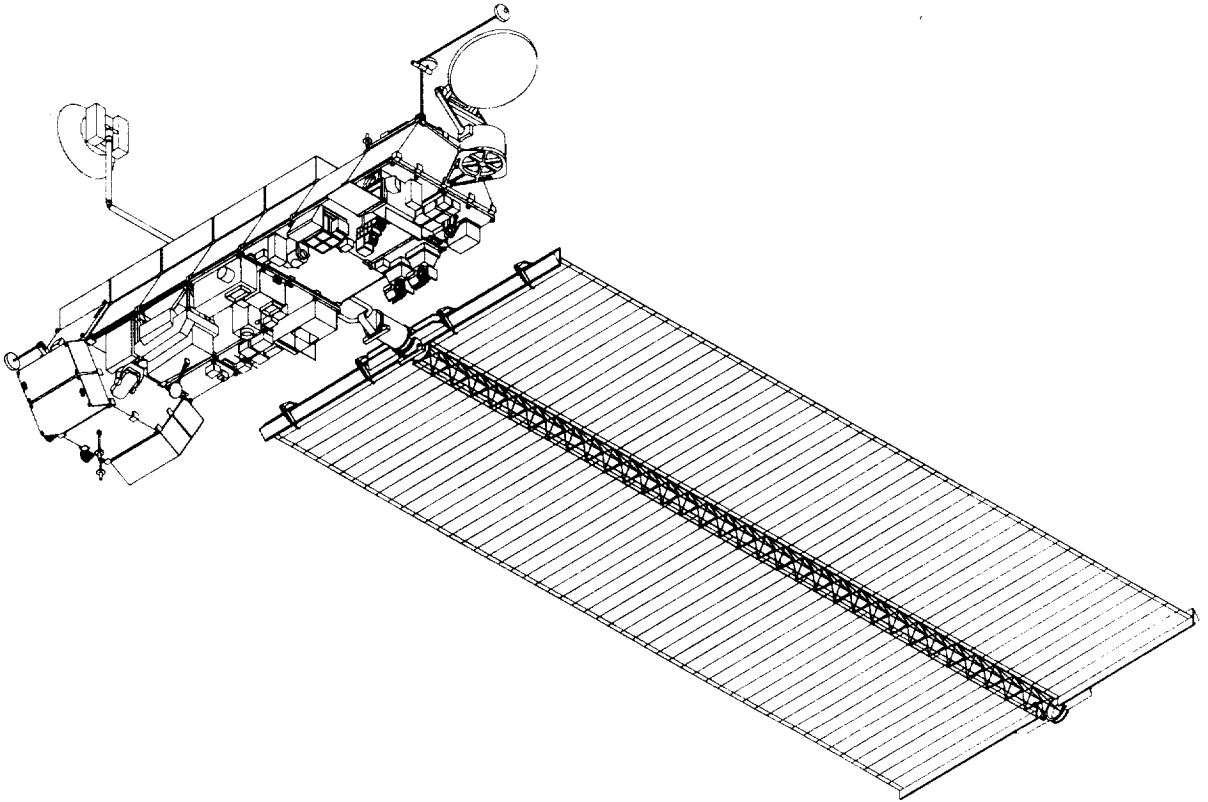
EOS-B

Platform Science Objectives:

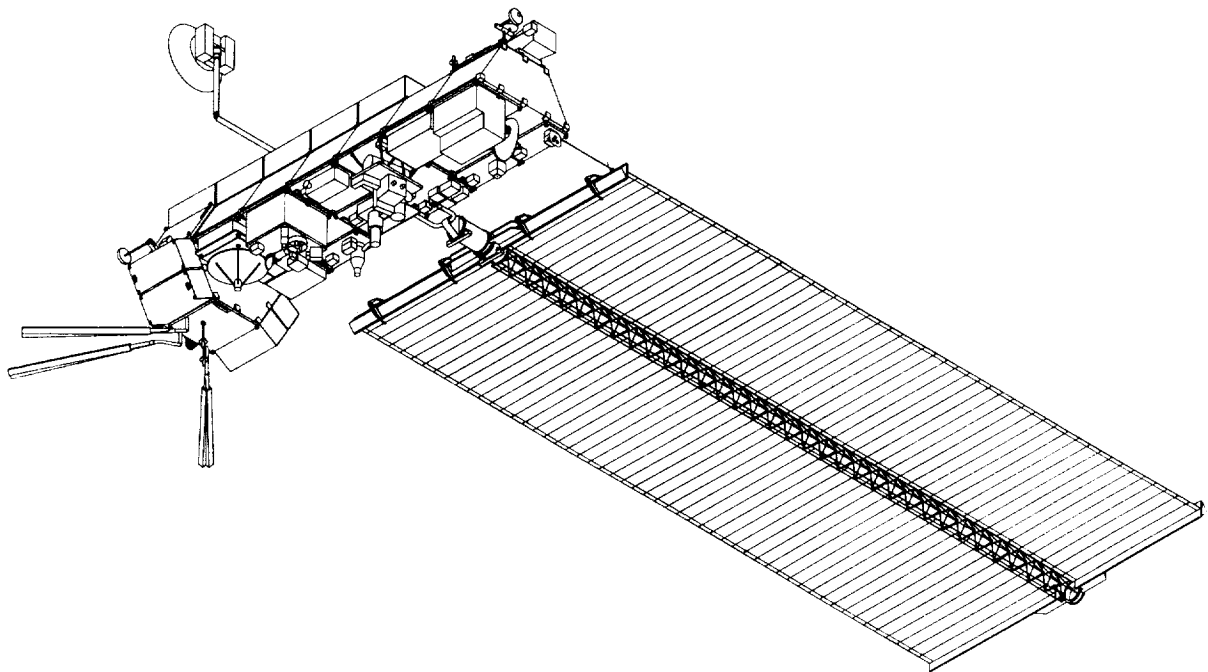
- Expanded Study of Stratospheric Ozone
 - Complete coverage of chemical species and winds
 - Much longer record than UARS (15 years vs. 1.5 years)
- First Global Monitoring of Tropospheric Chemistry
- Ocean Circulation and Air-Sea Interaction Measurements
 - Follow-on to TOPEX/Poseidon and NSCAT on ADEOS
- Study of Earthquakes and Growth/Mass Balance of Ice Sheets

Core Payload Candidates:

- Visible/Infrared Imagers: LIS
- Tropospheric Chemistry: TES
- Stratospheric Chemistry: SAFIRE, MLS, SWIRLS, SAGE III
- Tropospheric Winds: STIKSCAT/SCANSCAT
- Altimeter: ALT/RA
- Laser Ranging and Altimetry: GLRS



EOS-A



EOS-B

Figure 5. EOS-A and EOS-B Platforms

MISSION ELEMENTS

- Other Instruments: GGI, Communication Package, IPEI, GOS, XIE, SOLSTICE

Platform Design Capabilities: Copy of EOS-A design (see Figure 5).

Orbit Choice: 705 km, sun-synchronous, 1:30 pm equatorial crossing time.

EOS SAR

The EOS SAR instrument will be flown on a Delta-launched dedicated spacecraft due to its unique requirements. It is designed to monitor the following processes:

- Global deforestation and its impact on greenhouse gases
- Soil, snow, and canopy moisture and flood inundation, and their relationship to the global hydrologic cycle
- Sea ice properties and their effect on polar heat flux.

Current Design Plan: The EOS SAR platform has a 5-year design lifetime, a payload mass of 1,300 kg, 1.6 kW average power (5.8 kW peak power), and 15 Mbps average data rate (180 Mbps peak data rate). As with EOS-A and -B, the platform will be replaced twice to achieve a 15-year mission duration. The orbit will be at a 620-km altitude, sun-synchronous, with an afternoon equator crossing time. The EOS SAR is currently scheduled for a 1993/4 new start and a 1999 launch.

Attached Payloads

Three EOS instruments have been selected for definition-phase studies as candidates to fly attached to Space Station *Freedom* beginning in 1998. These instruments are duplicates of polar platform instruments. Flying in low-inclination orbit, attached payloads provide more frequent coverage of low-latitude regions (e.g., tropics) and temporal variation to monitor diurnal cycles. This compares to polar orbits that provide repetitive global coverage, but only observe each

location at the same time each day. The three candidate instruments are:

- LIS, which can observe the frequency and intensity of lightning at different times of day in low-mid-latitude regions
- CERES, which provides continuity in measurements of the Earth's radiation budget
- SAGE III, which measures atmospheric chemistry and is important for calibration of data from other sensors.

ESA EPOP-M1

Key Objectives:

- Primary Objectives
 - Environmental (pollution) monitoring
 - Atmospheric (climate) observations
 - Operational meteorology
 - Ocean and ice observations
- Secondary Objectives
 - Monitoring and management of the Earth's resources
 - Solid Earth research

Candidate Payload:

- Visible/Infrared Imagers: MERIS, AMRIR, POLDER
- Radiation Budget: CERES (1/2), POLDER, AATSR
- Atmospheric Sounding: SCIAMACHY, AMSU
- Active Microwave: AMI-2
- Stratospheric Chemistry: MIPAS, SCIAMACHY, DWS
- Tropospheric Winds: AMI-2

MISSION ELEMENTS

- Altimeter: RA
- Operational Instruments: AMRIR, AMSU, SEM, S&R
- Other Instruments: ARGOS, Communication Package

Current Design Plan: Current plans call for ESA EPOP-M1 to be based on the bus originally developed for SPOT-4. The M1 platform will be an enhanced version with a 4-year design life and 2 kW of average power, offering a nominal 1,700 kg of payload mass with possible expansion to 2,000 kg. The current reference altitude is about 800 km.

ESA EPOP- N1

Key Objectives:

- Resource Monitoring
 - Land surface properties
 - Vegetation cover, extent, and variation
 - Surface hydrological parameters
 - Snow and ice distribution
 - Geological features
- Environment and Atmosphere
 - Atmospheric chemistry
 - Aerosol distribution
- Operational Meteorology

Candidate Payload:

- Medium and High-Resolution Imaging Spectrometers
- Medium and High-Resolution Optical Imagers
- Imaging Radar (SAR)
- Passive Microwave Imaging Radiometers

Land:

SAR-2000
HIRIS and/or OMI/S-MOMS/SPOT-HRV
Derivatives

Atmosphere and Chemistry:

ATLID
AMAS
GOMOS*
ISAS
LISA
SCIAMACHY*

Operational Meteorology:

AMRIR
AMSU-A
MCP

* If not included on the first mission (EPOP-M1)

Actual payload definition will be determined by a variety of factors, such as the decisions on the first ESA and other international polar platforms, as well as technical considerations and availability of financial resources.

JPOP

The payload for the Japanese Polar Orbiting Platform is undefined at this time, except for a willingness by Japan to fly the NASA LAWS instrument. Additional candidate instruments have been considered, including a synthetic aperture radar, passive microwave sensor, and visible infrared spectrometers and radiometers. Actual payload definition will await decisions on the payloads of the other polar platforms (NASA and ESA), as well as development of ADEOS and availability of financial resources. Through participation in the EO-ICWG, Japan is involved in the considerations of how best to balance the full suite of required instrumentation across the available space resources.

Current Design Plan: Current plans call for JPOP design to be based on Japan's Advanced Earth Observation Satellite (ADEOS).

NOAA Polar Orbiting Environmental Satellites (POES)

Operational Objectives: NOAA's primary objectives are to provide, with very high reliability, daily global data for operational forecasts and warnings.

MISSION ELEMENTS

Planned Payload: AMRIR, AMSU, GOMR, SEM, S&R, ARGOS, Communication Package

Common Interfaces: NOAA operational instruments, along with the research instruments provided by NASA, ESA, and Japan, are being

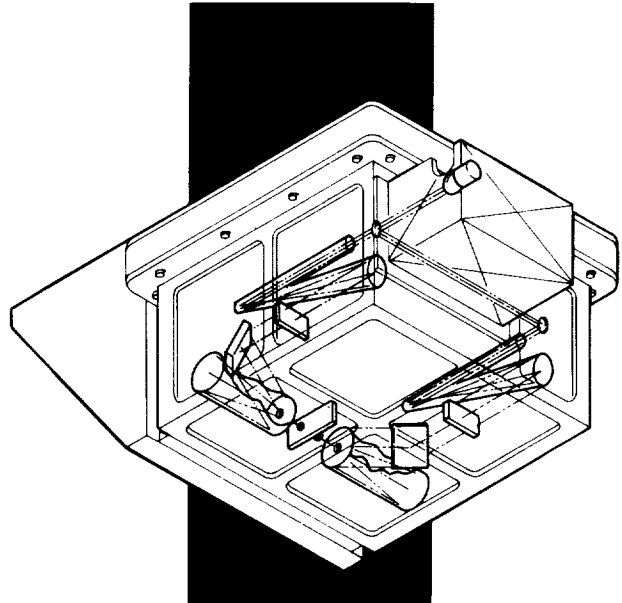
designed with common instrument/platform interfaces to facilitate possible future use of instruments on different platforms. For instance, NOAA might choose to fly NASA instruments currently designated as "pre-operational" on a continuation of the NOAA-O series afternoon spacecraft.

FACILITY INSTRUMENTS

AIRS/AMSU-A and -B
ALT
GLRS
HIRIS
LAWS
MODIS-N and -T
SAR
ITIR

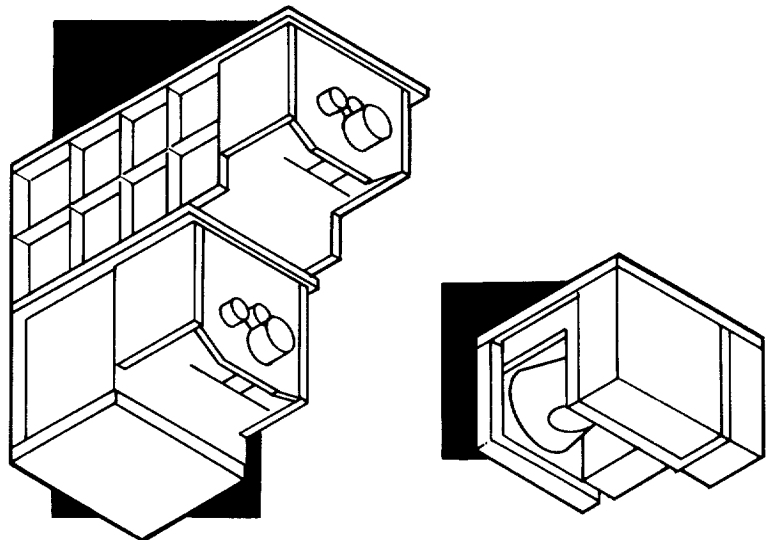
Atmospheric Infrared Sounder and Advanced Microwave Sounding Unit

- Atmospheric Infrared sounder
- Heritage: HIRS 2, HIS
- Measures the Earth's outgoing radiation between 3 and 17 microns



Atmospheric Infrared Sounder (AIRS)

- Microwave radiometers
- Heritage: MSU
- AMSU-A provides atmospheric temperature measurements from the surface up to 40 km
- AMSU-B provides atmospheric water vapor profile measurements



Advanced Microwave Sounding Unit (A and B)
(AMSU-A and -B)

The Atmospheric Infrared Sounder (AIRS) is a facility instrument selected by NASA to fly on the Earth Observing System (EOS) polar orbiting platform in the 1990s. The same platform will also carry the NOAA operational microwave sounder, the Advanced Microwave Sounding Unit (AMSU). AIRS is designed to meet NOAA's requirements for a high-resolution infrared sounder to fly on future operational weather satellites. Together AIRS/AMSU constitute the advanced operational sounding system, relative to the current HIRS/AMSU system. AIRS will measure the Earth's outgoing radiation, between 3 and 17 microns, simultaneously in 4,000 high spectral-resolution channels. This is supplemented with five channels in the visible range between 0.4 and 1.1 microns. AIRS has a field-of-view of 1.1° and ±49° scanning capability perpendicular to the spacecraft ground-track.

The AIRS optical system is designed as a grating spectrometer using cooled HgCdTe photovoltaic detectors arranged in several linear arrays. In order to optimize the design for maximum signal-to-noise ratio, the instrument employs two separate spectrometers sharing a common scan mirror and covering the wavelength regions 3 to 8 microns and 8 to 17 microns, respectively. AIRS has a mass of 80 kg, data rate of 1.5 Mbps, and requires 300 watts of power.

AMSU is a microwave radiometer providing measurements of atmospheric temperature and humidity. It is a 20-channel instrument divided into AMSU-A and AMSU-B subsystems. AMSU-A primarily provides atmospheric temperature measurements from the surface up to 40 km in 15 channels, (i.e., 23.8 GHz, 31.4 GHz, 12 channels between 50.3 to 57.3 GHz, and 89 GHz). Coverage is approximately 50° on both sides of

the suborbital track, with an IFOV of 3.3°. Temperature resolution is equivalent to 0.25 to 1.3 K.

AMSU-B primarily provides atmospheric water vapor profile measurements in five channels at 89 GHz, 166 GHz, and 183 GHz (3). Coverage is the same as AMSU-A, with an IFOV of 1.1° and a temperature resolution of 1.0 to 1.2 K.

AIRS and AMSU measurements will be analyzed jointly to provide day and night data on:

- Atmospheric temperature profiles with 1°C accuracy and 1-km vertical resolution
- Relative humidity profiles and total precipitable water vapor
- Fractional cloud cover, cloud infrared emissivity, and cloud-top pressure and temperature
- Total ozone burden of the atmosphere
- Mapping of the distribution of minor gases such as CH₄, CO, and N₂O
- Sea surface temperature with an average accuracy of 1°C
- Land surface temperature and infrared spectral emissivity
- Surface albedo
- Snow and ice cover
- Outgoing long-wave radiation
- Precipitation index.

AIRS & AMSU

Team Leader

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

Moustafa Chahine

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 as well. 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/LMD
Henry E. Fleming, NOAA/NESDIS
Catherine Gautier, Scripps Institution of
Oceanography
John Francis LeMarshall, Bureau of
Meteorology Research Centre
Larry M. McMillin, U.S. Department of
Commerce
Ralph Alvin Petersen, NOAA/NWS/NMC

Henry E. Revercomb, University of Wisconsin
Rolando Rizzi, Università di Bologna
Phillip 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

AIRS Parameters

Mass = 80 kg
Instrument duty cycle = 100%
Average power = 300 W (RMS)
Peak power = 350 W (instrument cleaning)
Heater power = 25 W (replacement)
Thermal control by active refrigerator, passive cooling, and multi-layer insulation.
Requires clear space view and clear Earth view.
Thermal operating range: Instrument = 150 K Detector = 60 K
Average data rate = Peak data rate = 1.5 Mbps
Pointing requirements (spacecraft + instrument):
 Control = 0.1° Knowledge = 0.1° Stability = 0.05°
Instrument view angle = $\pm 52^\circ$ cone relative to nadir and $\pm 3^\circ$ space view from perpendicular to spacecraft velocity vector, $\geq 90^\circ$ from nadir
Instrument IFOV = 1.1° diameter (approximately 11 km from 705-km orbit)
No special contamination sensitivity
Physical size = 0.5 m x 0.5 m x 0.5 m

Note: Cold space calibration positions at 6.6° and 9.9° declination relative to the orbit plane.

AMSU-A Parameters

Mass = 82 kg
Instrument duty cycle = 100%
Average power = Peak power = 122 W
Heater power = TBD
Passive thermal control
Average data rate = 6.5 kbps
Pointing requirements (spacecraft + instrument):
 Control = $\pm 0.2^\circ$ Knowledge = $\pm 0.1^\circ$ Stability = 0.05°
Instrument view angle = $\pm 49.5^\circ$ cross-track from nadir
Instrument IFOV = 3.3°
No special contamination sensitivity
Physical size = AMSU-A1 = 30.5 cm x 73.1 cm x 61 cm; AMSU-A2 = 66.8 cm x 61 cm x 69.6 cm

Notes: 3 command-selectable cold space positions for 3.3° beam: 6.6° (primary), 9.9° , 13.2° declination relative to the orbit plane. Data based on Contract Attachment B (S-4870-13) "Performance and Operation Specification for the Advanced Microwave Sounding Unit-A," August 1984.

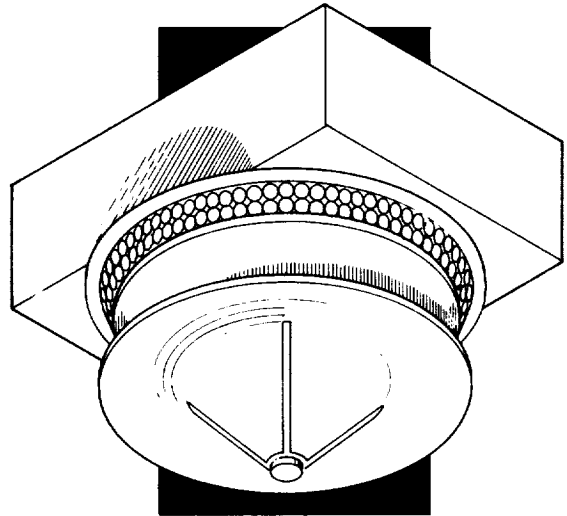
AMSU-B Parameters

Mass = 29 kg
Instrument duty cycle = 100%
Average power = Peak power = 82.3 W
Heater power = TBD
Passive thermal control
Average data rate = 4.2 kbps
Pointing requirements (spacecraft + instrument):
 Control = $\pm 0.1^\circ$ Knowledge = $\pm 0.05^\circ$
Instrument view angle = $\pm 49.5^\circ$ cross-track from nadir
Instrument IFOV = 1.1°
No special contamination sensitivity
Physical size = 65 cm x 64 cm x 45.8 cm

Note: Cold space calibration positions

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 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, the primary contribution of ALT to EOS objectives and global change research is to provide information on the ocean surface current velocity, which, when combined with ocean models, can lead to a four-dimensional 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 contributions of ALT lie in

areas including 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. The altimeter is a dual frequency radar operating at 13.6 GHz (Ku-band) and 5.3 GHz (C-band). The Ku-band is the primary channel for altitude measurement. The C-band is for correction for the pulse delay in the ionosphere. The instrument precision for altitude measurement is 2 cm. The footprint of the instrument varies from 2 to 10 km depending on ocean wave height.

ALT Parameters

Mass = 275 kg
Instrument duty cycle = 100%
Transmitter duty cycle = 12% (C-band), 45% (Ku-band)
Average power = 232 W
Peak power = 250 W (calibration, once per day)
Peak transmitter power = 22 W (for each transmitter)
Heater power = ~150 W (replacement)
Active thermal control
Thermal operating range = 0° to 35°C; 15°C gradient
Average data rate = Peak data rate = 80 kbps
Pointing requirements (Instrument): Control = 0.14°;
Knowledge = 0.07°; Stability = 0.0125° per second
Instrument view angle = nadir
Instrument beam divergence = 10° conic section
intersecting antenna reflector edge
No contamination sensitivity
Physical size not to exceed 0.3 cubic meters

Team Leader

Lee-Lueng Fu received his B.S in physics from the National Taiwan University in 1972, and his Ph.D. in oceanography from Massachusetts Institute of Technology and Woods Hole Oceanographic Institution in 1980. He has been with the Jet Propulsion Laboratory (JPL) 1980, and is currently Supervisor of the Physical Oceanography Group, Atmospheric and Oceanography Sciences Section. Dr. Fu's research interests are in the area of 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

Lee-Lueng Fu

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.

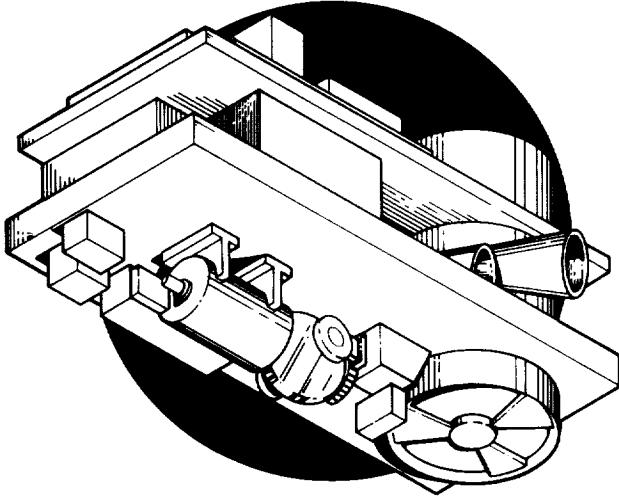
Team Members

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
 Yves Desaubles, 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
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 Karrel Wakker, Delft University of Technology, The Netherlands
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 Carl Wunsch, Massachusetts Institute of Technology

Note: The TOPEX/Poseidon Science Working Team forms an interim EOS ALT Team. An Announcement of Opportunity for EOS ALT will be released a year after TOPEX/Poseidon launch, but not later than 2 years prior to EOS launch.

Geoscience Laser Ranging System



GLRS is a laser ranger and altimeter designed to measure geodynamic, ice sheet, cloud, and geological processes and features. Crustal movements will be monitored to detect strain accumulation in seismic zones and deformations near tectonic plate boundaries. Crustal deformations 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 millimeters. 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 centimeters, 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 be determined. The accuracy of height determinations over land will be assessed

- 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

using ground slope and roughness. The height distribution will be digitized over a total dynamic range of several tens of meters. 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 tripled, mode-locked, solid-state Nd:YAG laser with energy levels of 120 mJ (1064 nm), 60 mJ (532 nm), and 40 mJ (355 nm). The pulse repetition rate is 40 pps and the beam divergence is approximately 0.1 mrad. The 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 degrees from nadir and the receiving telescope has a diameter of 18 cm. The altimeter channel uses a 50-cm diameter telescope.

GLRS Parameters

Mass = 350 kg
 Instrument duty cycle = TBD ($\geq 16\%$) by available power and laser lifetime
 Average power = TBD with duty cycle, 300 W for standby
 Peak power = 650 W (data taking)
 Heater power = TBD
 Active and passive thermal control
 Thermal operating range = $\sim 20^\circ\text{C}$
 Average data rate = TBD with duty cycle, about 1% of peak for housekeeping
 Peak data rate = 800 kbps (data taking)
 Pointing requirements (ranger) Pointing requirements (platform, altimeter fixed at nadir):
 control = 10 arcsec control = 3 arcsec min
 knowledge = 5 arcsec knowledge = 5 arcsec
 stability = not a driver stability = not a driver
 Instrument view angle = 50° cone about nadir (ranger); 0.1 mrad (altimeter beam divergence)
 Instrument IFOV = $100 \mu\text{rad}$ within new angle (ranger); $100 \mu\text{rad}$ fixed at nadir (altimeter)
 Contamination sensitivity = TBD
 Physical size = about 1.5 m x 1.5 m x 1.5 m

Team Leader

Steven Cohen earned a Ph.D. in physics from the University of Maryland in 1973, and has been affiliated with Goddard Space Flight Center (GSFC) for over 20 years; since 1976 he has been with the Geodynamics Branch as a Research Geophysicist. During this time he has conducted basic geophysics research on the scientific issues to be addressed by GLRS, including earthquake-related crustal deformations, tectonic plate motions, and plate interactions. He has also been responsible for assessing the geodetic capabilities of spaceborne laser ranging systems, such as GLRS, for geodynamic and geophysical research. In his earlier position with GSFC's Laser Technology Branch, he became familiar with laser operation, requirements, and technical issues and published a variety of journal papers and reports on both lasers and laser detectors.

Steven Cohen

Dr. Cohen was the sole geodynamics representative to EOS's Lidar Atmospheric Sounder and Altimeter Panel; subsequently, he formed a science/engineering committee that completed the conceptual design of GLRS and was appointed GLRS Acting Team Leader when the system was assigned to GSFC development.

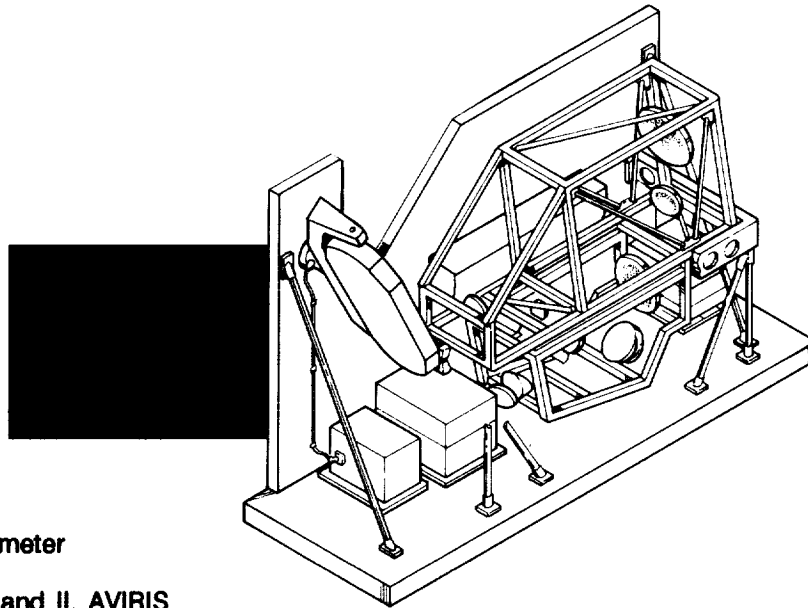
Dr. Cohen has published some 75 technical articles, and co-authored the NASA report on space technology geodesy and its application to crustal dynamics, which became the basis for the current Geodynamics Program and Crustal Dynamics Project. At present he is editor of an American Geophysical Union monograph on deformation and transmission of stress in the Earth.

Team Members

Charles R. Bentley, University of Wisconsin
 Michael G. Bevis, North Carolina State Univ.
 Jack L. Bufton, 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
 Bob E. Schutz, University of Texas, Austin
 James D. Spinhirne, Goddard Space Flight Center
 Robert H. Thomas, Joint Oceanographic Institutions, Inc.
 H. Jay Zwally, Goddard Space Flight Center

High-Resolution Imaging Spectrometer



- 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 covers the 0.4 to 2.45 μm wavelength region in 192 spectral bands, has a nadir pixel size of 30 m, and a swath width of 24 km. HIRIS has a mass of 450 to 650 kg, requires 300 W average power, and provides 100 Mbps of data to the platform. The duty cycle is less than 8 percent.

These capabilities make it possible to address a number of scientific questions that fall into three categories: processes, interfaces, and scaling.

Processes. HIRIS will provide the measurements necessary to study and understand many of the fundamental processes of importance at global scales. Biogeophysical measurements at HIRIS spatial and spectral resolution will lead to better understanding of Earth system processes,

permitting new biospheric models to be developed and existing process models to be improved, initialized, and validated.

Interfaces. HIRIS will permit detailed examination and monitoring of sensitive ecosystem interfaces where rates of change are highest, therefore most readily detected. Changes are best detected at interfaces--such as the montane snow line, the savana-woodland border, the wetland-upland edge, and the estuarine-oceanic zone.

Scaling. HIRIS operates at the intermediate scale between the human and the global, thus is essential to link 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.

HIRIS Parameters

Mass = 450 to 650 kg
 Instrument duty cycle = 8%
 Average power = 300 W
 Peak power = 600 W (\leq 8% duty cycle)
 Heater power = TBD
 Passive thermal control
 Thermal operating range:
 Infrared detector = 130 K Structure and optics = 300 K
 Visible detector = 300 K Electronics = TBD
 Average data rate = 3 Mbps (\geq 1 week)
 = 10 Mbps (worst case 2 orbits)
 Peak data rate = 100 Mbps (peak buffered output,
 including editing and compression)

Pointing requirements (instrument + spacecraft):
 control = 293 arcsec (3 sigma total)
 knowledge = 117 arcsec (3 sigma total; pending
 final science team approval)
 stability = 2.6 arcsec per 35 ms, 9 arcsec per 34
 seconds (3 sigma total)
 Instrument view angle = $+52^{\circ}$ to -30° along-track;
 $\pm 45^{\circ}$ cross-track
 Instrument IFOV = 30 m (projected FOV = 24-km cross-
 track by 30 m down-track, projected at nadir)
 Sensitive to contamination: optical and radiator surfaces
 provided with protective covers
 Physical size: 48" x 36" x 91"

Team Leader

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. Presently, he is a Professor in the Department of Geological Sciences and Director of the Center for the Study of Earth from Space/CIRES at the University of Colorado. His current scientific 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 Imaging Spectro-

Alexander Goetz

meter Program Manager for JPL 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.

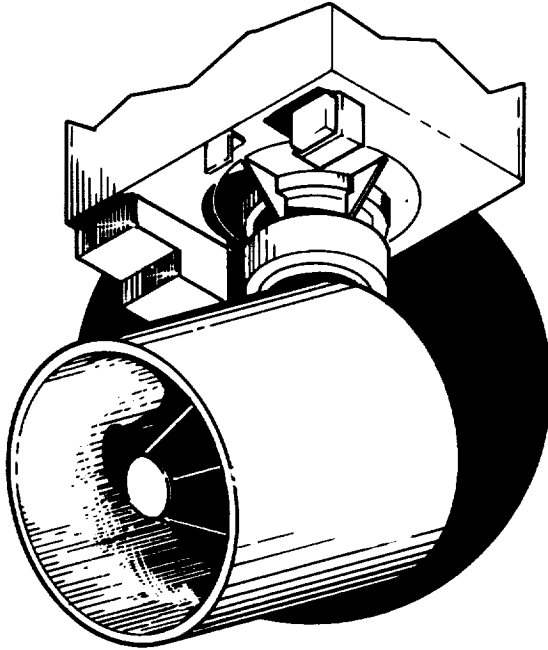
Dr. Goetz's other activities mirror these interests. In addition to being well-published in the current literature, he serves on several advisory boards for the National Research Council; has consulted with private industry both in the U.S. and abroad; has taught an independent short course in advanced 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

Laser Atmospheric Wind Sounder



- Doppler lidar system
- Heritage: ground, aircraft, and concept 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 to advancing our understanding and prediction of the total Earth system. The key EOS objectives that LAWS data will help meet are: (1) determining what factors control the hydrologic cycle (specifically, a more accurate estimate of the horizontal transport of water vapor can be determined and, through their use in global models using four-dimensional data assimilation, LAWS will improve the depiction of vertical motion and precipitation), (2) quantifying the global distribution and transport of tropospheric gases and aerosols, (3) determining the relationships between large-scale and low-frequency variability of meteorological observables, (4) improving the accuracy of deterministic weather forecasting and extending the useful forecast period, and (5) determining the global heat, mass, and momentum coupling between the

ocean and atmosphere. Fluxes of momentum, heat, moisture, CO₂, and other constituents are important to a majority of the EOS interdisciplinary studies. These fluxes are inevitably parameterized with respect to a mean horizontal wind in the boundary layer. At a minimum, LAWS will provide complementary data to the scatterometer over water and to boundary layer wind measurements.

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

LAWS has also been approved for concept study on the manned Space Station. Professor T.N. Krishnamurti, Florida State University, is the PI for that effort.

LAWS Parameters

Mass = 875 kg
Instrument duty cycle = 100%
Average power = Peak power = 3.0 kW
Heater power = 0.6 kW
Active thermal control
Thermal operating range: TBD
Average data rate = Peak data rate = 1.5 Mbps
Pointing requirements:
 control = 100 arcsec
 knowledge = 25 arcsec
 stability = 0.4 arcsec per 5 second
Instrument view angle = conical beam 45° off nadir
Limited susceptibility to particulate and molecular contamination
Physical size = about 4 m x 2 m x 2 m (stowed)
Note: Data are from Phase A concept studies and will be refined during the definition phase.

Team Leader

Wayman Baker is Deputy Chief of the Development Division at the National Meteorological Center of the NOAA. Blending academic skills in mathematics and the atmospheric sciences (Ph.D. 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 the LAWS

Wayman Baker

instrument 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, a NOAA Performance Award in 1989, and was elected Fellow of the American Meteorological Society in 1989.

Team Members

John R. Anderson, University of Wisconsin
Robert M. Atlas, Goddard Space Flight Center
George Emmitt, Simpson Weather Associates, Inc.

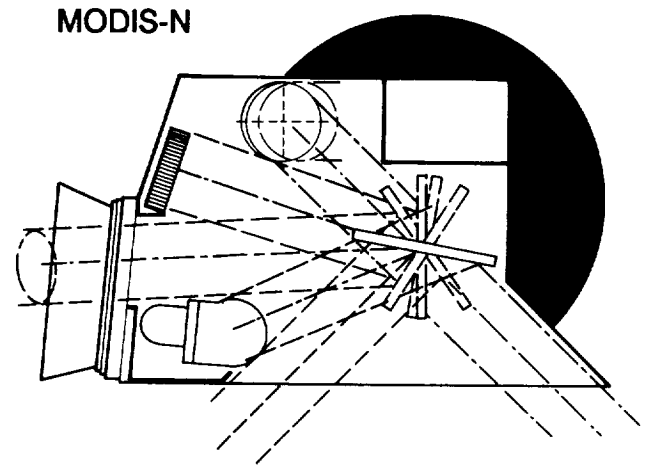
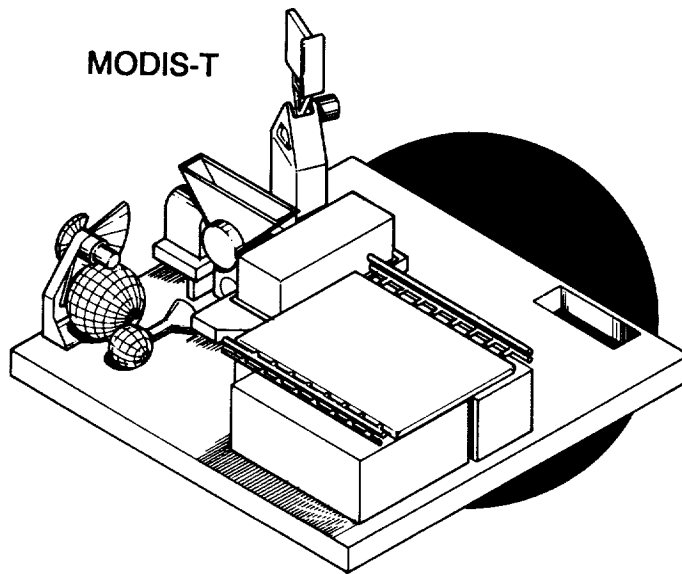
Dan Fitzjarrald, Marshall Space Flight Center
R. Michael Hardesty, NOAA/ERL/WPL
T.N. Krishnamurti, Florida State University
Robert W. Lee, Lassen Research
Andrew Lorenc, Meteorological Office
Robert Menzies, Jet Propulsion Laboratory

Timothy L. Miller, Marshall Space Flight Center
Madison Post, NOAA/ERL/WPL
Robert A. Brown, University of Washington
John Molinari, State University of New York
Jan Paegle, University of Utah

Associate Member

David Bowdle, University of Alabama

Moderate-Resolution Imaging Spectrometer-Nadir/Tilt



- 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, Nimbus 7 CZCS
- Both measure biological and physical processes
- A table of Instrument characteristics and measurement parameters is given in the Appendix

MODIS-T is an imaging spectrometer for the measurement of biological and physical processes on a 1 km x 1 km scale with emphasis on the study of ocean primary productivity. It is a scanning instrument covering a 1,500-km swath centered at nadir, with a $\pm 50^\circ$ tilt capability for sun-glint avoidance and the examination of the bidirectional reflectance distribution function (BRDF) of large homogeneous targets. It has a spectral range of 0.4 to 0.88 μm divided into 64 bands. MODIS-T has a mass of approximately 140 kg, a data rate of 3 Mbps, and requires 130 watts of power. MODIS-T is baselined for the EOS-A polar platform.

MODIS-N is a companion instrument to MODIS-T and is an imaging spectrometer used for the

measurement of biological and physical processes that do not require off-nadir, fore and aft pointing. It has pixel sizes of 214 m, 428 m, and 856 m. It is a scanning instrument with a swath width of 2,300 km. It samples the spectral ranges of 0.4 μm to 14.54 μm using 36 bands. MODIS-N is expected to have a mass of 200 kg, peak data rate of 8.3 Mbps (during daytime hours), and requires 250 watts of power. MODIS-N is baselined for the EOS-A polar platform.

A Tropical Region Imaging Spectrometer (TRIS) is a modified copy of MODIS-N and -T that has been approved for concept study on the manned Space Station. William L. Barnes, Goddard Space Flight Center, is the PI for that effort.

MODIS-T Parameters

Mass = ~140 kg
 Instrument duty cycle = 100% (day only)
 Average power = ~130 W
 Peak power = 135 W
 Heater power = 22.6 W
 Thermal control by cold plate
 Thermal operating range = 5°C to 25°C
 Average data rate = 1.4 Mbps
 Peak data rate = 3.5 Mbps (40% duty cycle, daytime only)
 Pointing requirements (spacecraft + instrument):
 control = 95 arcsec (3 sigma)
 knowledge = 60 arcsec (1 sigma)
 stability = 15.6 μrad
 Instrument view angle = 90°, ± 45° (1500 km) cross-track
 ± 50° in-track tilt centered at nadir
 Instrument IFOV = 1.56 mrad (1.1 km)
 Optics have moderate contamination sensitivity
 Physical size = 75 cm x 140 cm x 100 cm

MODIS-N Parameters

Mass = ~200 kg
 Instrument duty cycle = 100%
 Average power = 250 W
 Peak power = 262 W
 Heater power = 3 W
 Passive thermal control
 Thermal operating range = +5°C to 25°C
 Average data rate = 11.4 Mbps
 Peak data rate = 15 Mbps (daytime, 40%)
 Pointing requirements (spacecraft + instrument):
 control = 95 arcsec (3 sigma)
 knowledge = 60 arcsec (1 sigma)
 stability = 15.6 μrad
 Instrument view angle = 100°, ± 55° (2330 km) cross-track, fixed at nadir
 Instrument IFOV = 1.21 mrad (856 m), 0.607 mrad (428 m), 0.303 mrad (214 m)
 Optics and passive cooler have moderate contamination sensitivity
 Physical size = 1 m x 1.6 m x 1 m

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 GSFC. He was recently appointed Director for 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 4 years. He also has over a dozen years 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 exper-

Vincent V. Salomonson

ience includes over 15 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.

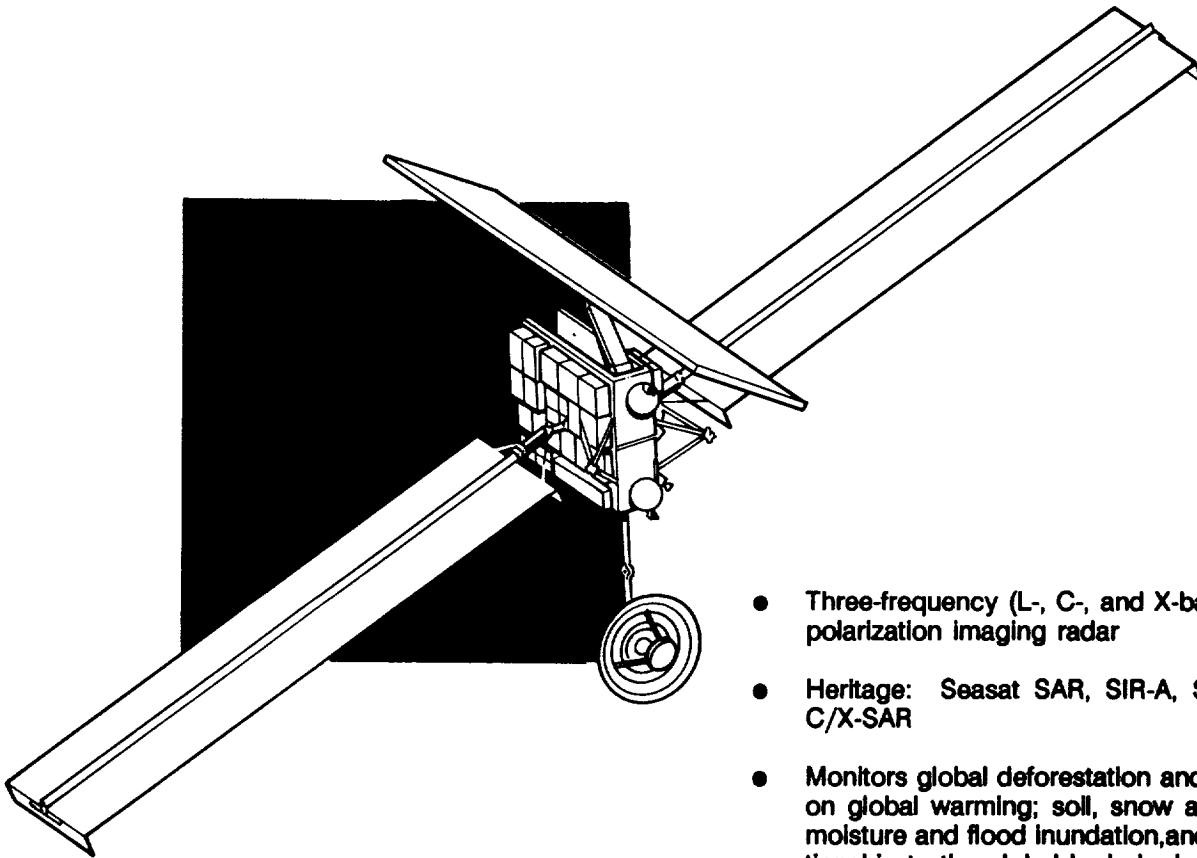
Cited on numerous occasions for his outstanding research and scientific achievement, Dr. Salomonson is the recipient of seven NASA awards for exceptional achievement, service, and performance; the Distinguished Achievement Award of the IEEE Geoscience and Remote Sensing Society; the William T. Pecora Award; and the Distinguished Alumnus Award from Colorado State University.

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, University of Maryland

Yoram J. Kaufman, Science Systems & Applications, Inc.
 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
 Joel Sussekind, Goddard Space Flight Center
 Didier Tanre, Univ. des Sciences et Techniques de Lille
 Vern Vanderbilt, Ames Research Center
 Zhengming Wan, Institute of Remote Sensing Application

EOS Synthetic Aperture Radar



- Three-frequency (L-, C-, and X-band), multi-polarization 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

The EOS Synthetic Aperture Radar (EOS SAR) will monitor 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.

The EOS SAR is a three-frequency (L-, C-, and X-band), multipolarization instrument providing HH and VV plus cross-polarization and phase measurements. The X-band is to be provided by the Federal Republic of Germany with the collaboration of Italy. The instrument uses electronic beam steering in the cross-track direction to acquire images at selectable inci-

dence angles from 15 to 50 degrees. The EOS SAR has a varying spatial resolution and swath width capability in three distinct 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 by a Delta II class vehicle to be launched concurrent with the EOS-A and EOS-B platforms.

EOS SAR Parameters

Mass = 1300 kg
Instrument duty cycle = 60%
Average power = 1.6 W
Peak power = 5.8 kW
No thermal control required
Thermal operating range = TBD
Average data rate = 15 Mbps
Peak data rate = 180 Mbps
Pointing requirements (Instrument):
 control = 0.5°
 knowledge = 0.05°
 stability = 0.01°
Instrument view angle = 15° to 40° look angle from nadir, both sides of nadir
Contamination sensitivity is TBD

Team Leader

Charles Elachi received his undergraduate degree in physics from the University of Grenoble in France in 1968, and went on to earn his Ph.D. in electrical sciences from the California Institute of Technology. He holds a second M.S. degree 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 and the California Institute of Technology since 1971; in addition to lecturing at CIT, he is JPL's Assistant Lab 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 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

Charles Elachi

SIR-B, and is the Team Leader on SIR-C; 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.

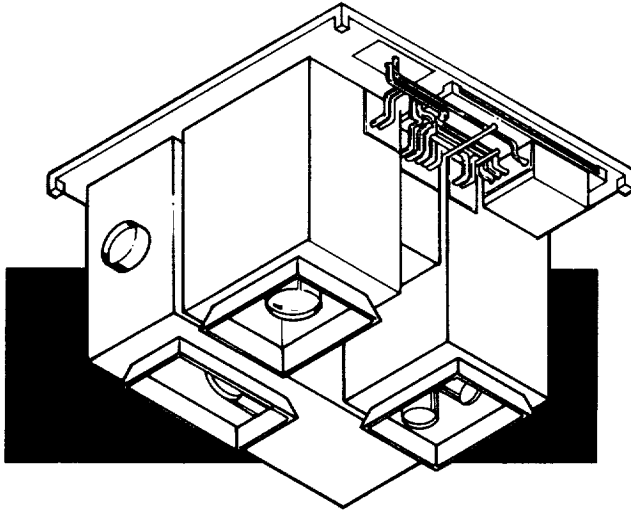
Among his other professional activities, he participates with numerous committees, commissions, working groups, and advisory boards; most relevant in this context was his role as Co-Chairman of the EOS Science SAR Panel from 1985 to 1987. Dr. Elachi was recently elected to the National Academy of Engineering and as 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, USDA/Agricultural Research Service
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

Intermediate Thermal Infrared Radiometer (ITIR)



- Imaging radiometer
- Heritage: JERS-1
- Provides high spatial resolution images of the land, surface, water, and clouds
- Multi-spectral channels from visible to thermal infrared
- Instrument characteristics are detailed in the Appendix

ITIR's science objectives involve surface and cloud imaging with spatially high resolutions and with multi-spectral channels from visible to thermal infrared. Thermal infrared (TIR) science objectives include classification of rock types (felsic-mafic), examination of clouds and their radiative role, evapotranspiration, vegetation, and volcanology. Short wavelength infrared (SWIR) science objectives include classification of rock types (altered rocks, carbonate rocks).

Visible and near infrared (VNIR) science objectives include providing baseline data for synergistic interpretation with TIR and SWIR data and geomorphology through stereo data acquisition. ITIR can operate simultaneously in all bands with HIRIS and MODIS-N, and AIRS for atmospheric correction. The TIGER Team, headed by Dr. Anne Kahle, is cooperating with the ITIR instrument development effort.

ITIR Parameters

Mass = 345 kg
Instrument duty cycle = 33%
Average power = 450 W
Peak power = 650 W (~10% of orbit)
Thermal control by radiator and thermal loop
Thermal operating range = 0° to 40°C
Average data rate = 12.7 Mbps
Peak data rate = 88 Mbps (~16% of orbit)
Pointing requirements not available.

Five instrument view angles:

- 1 = Elliptical cone along nadir (z-axis) 16° about x-axis by 27° about y-axis
 - 2 = 16° cone about nadir
 - 3 = 16° cone about nadir
 - 4 = 60° cone about y-axis
 - 5 = 15° cone about axis rotated 30° to z-axis from x-axis and 75° to y-axis from x-axis
- Contamination sensitivity not available
Physical size = 1.5 m x 1.5 m x 0.9 m

Team Members

Akira Ono, MITI
Y. Ishii, Tokyo University
Hiroji Tsu, Geological Survey of Japan
Hiroyuki Fujisada, Electro Technical Laboratory

U.S. Endorsements

Anne B. Kahle, Jet Propulsion Laboratory
Phillip N. Slater, University of Arizona
Ronald Welch, Naval Oceanographic & Atmospheric Research Laboratory

TIGER Team Members

Francois Becker, Universite Louis Pasteur de Strasbourg
Stillman Chase, Santa Barbara Research Center
Philip R. Christensen, Arizona State University
Alan R. Gillespie, University of Washington
Andrew Green, CSIRO
Hugh H. Kieffer, U.S. Geological Survey
Frank Palluconi, Jet Propulsion Laboratory
David Pieri, Jet Propulsion Laboratory
Lawrence C. Rowan, Johns Hopkins University
John W. Salisbury, U.S. Geological Survey
Jerry Solomon, Jet Propulsion Laboratory
James Young, Santa Barbara Research Center
Thomas Schmugge, USDA/Hydrology Laboratory

INSTRUMENT INVESTIGATIONS

ACRIM, Richard C. Willson
CERES, Bruce Barkstrom
ENACEOS, Barry H. Mauk
EOSP, Larry D. Travis
GGI, William G. Melbourne
GOS, Robert Langel, III
HIMSS, Roy W. Spencer
HIRDLS, John Barnett & John Gille
IPEI, Roderick Heelis
LIS, Hugh Christian
MISR, David J. Diner
MLS, Joe W. Waters
MOPITT, James Drummond
POEMS, Paul A. Evenson
SAFIRE, James M. Russell, III
SAGE III, M. Patrick McCormick
SCANSCAT/STIKSCAT, Michael Freilich
SOLSTICE, Gary Rottman
SWIRLS, Daniel J. McCleese
TES, Reinhard Beer
TRACER, Henry G. Reichle, Jr.
TRAMAR, Gerald North
XIE, George K. Parks

ACRIM

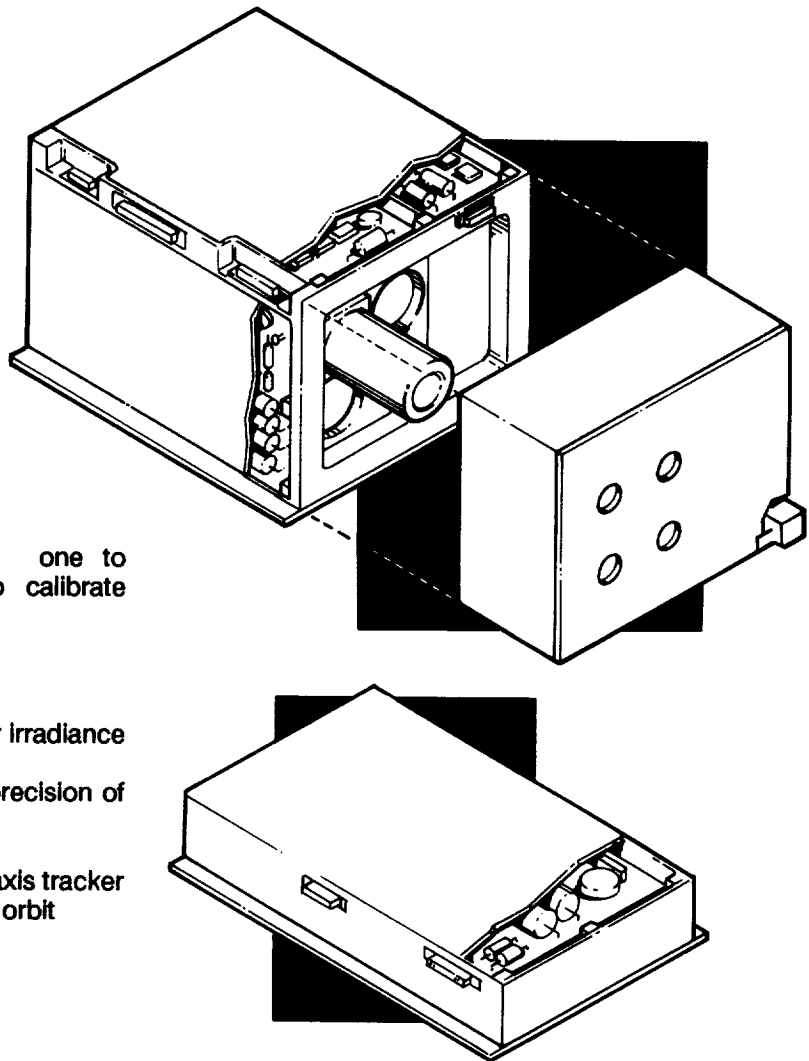
Active Cavity Radiometer Irradiance Monitor

The Active Cavity Radiometer Irradiance Monitor (ACRIM) experiment is designed to implement an "overlap strategy" with earlier ACRIM experiments and within the EOS mission itself, which is required to sustain the NASA long-term solar luminosity data base throughout the EOS mission time frame. The primary objective of

ACRIM is to monitor the variability of total solar irradiance with state-of-the-art accuracy and precision, thereby extending the high-precision data base compiled for NASA since 1980 by other ACRIM experiments as part of the Earth radiation budget "principal thrust" in the National Climate Program.

THE ACRIM INSTRUMENT

- 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
- SI 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



ACRIM Parameters

Mass = 25 kg

Instrument duty cycle = 100%

Average power = 10 W

Peak power = 15 W (shutter operation transient)

Passive thermal control

Thermal operating range = -10°C to 55°C

Average data rate = Peak data rate = 512 bps

Pointing requirements (Instrument):

control = 0.1°

knowledge = 0.05°

stability = 0.05°

Note: tolerance for off-target (sun) pointing is 0.5°

Instrument view angle = $\pm 5^\circ$ with respect to instrument viewing angle (aligned on sun)

IFOV = $\pm 2.5^\circ$ with respect to instrument viewing angle (aligned on sun)

High sensitivity to molecular and particulate contamination. Protection is integral to instrument design.

Physical size:

sensor assembly = 0.6 m x 0.6 m x 0.6 m

electronics assembly = 0.25 m x 0.50 m x 0.15 m

Richard C. Willson, Principal Investigator

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 JPL. His career, which began at JPL in 1963, has been involved primarily with development of state-of-the-art Active Cavity Radiometer pyrhellometry 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 1, Space Shuttle Spacelab 1, ATLAS I and ATLAS II/ACR, and Upper Atmosphere Research Satellite ACRIM II experiments.

Co-Investigator

Hugh S. Hudson, University of California, San Diego

CERES

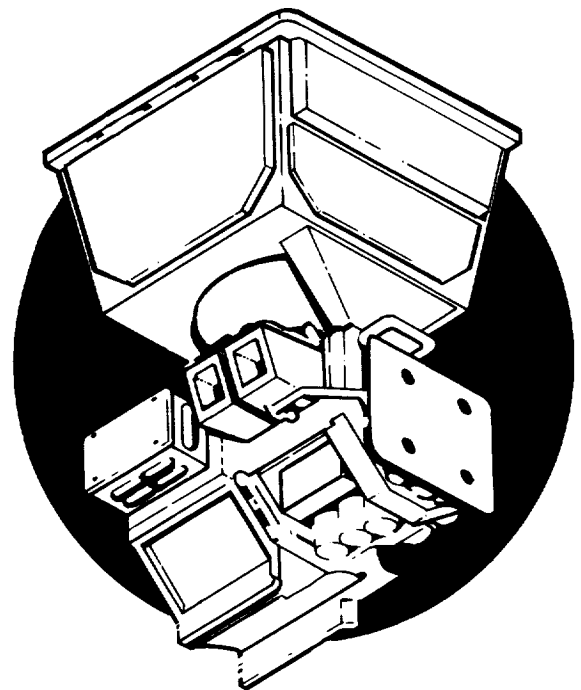
Clouds and the Earth's Radiant Energy System

The instruments of the Clouds and the Earth's Radiant Energy System (CERES) Investigation will provide EOS with an accurate and consistent radiation data base. Thus, these instruments will continue the long-term measurement of Earth's radiation budget. CERES will also provide global measurements of atmospheric radiation from the top of the atmosphere to the surface. This work will deepen understanding of the climate system and of atmospheric and oceanic energetics. It will also support extended-range numerical weather prediction. The CERES instruments are a pair of broadband, scanning radiometers

based on the Earth Radiation Budget Experiment (ERBE) scanners. This design provides them with a space-flight-proven heritage and excellent calibration traceability and stability. CERES will provide radiation data as fluxes at the top of the Earth's atmosphere, at the Earth's surface, and as flux divergences within the atmosphere. CERES also will provide such cloud data as areal coverage, altitude, condensed-water density, and shortwave and longwave optical depths. An attached payload version gives increased diurnal sampling of the tropics from the Space Station.

CERES INSTRUMENT

- 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 $>100 \mu\text{m}$), shortwave (0.2 to $3.5 \mu\text{m}$), and longwave (6 to $25 \mu\text{m}$)
- Thermistor bolometer detector: spectral separation through various filters



CERES Parameters (polar platform and space station)

Mass = 45 kg per scanner package (90 kg for two packages on a spacecraft)

Average power = 90 W (2 instruments)

Peak power = 120 W (2 instruments)

Duty cycle = 100%

Heater power = TBD (Phase B)

Passive thermal control

Thermal operating range: can operate over wide range of temperatures; detectors controlled accurately near 37°C

Average data rate = Peak data rate = 10 kbps (2 instruments)

Pointing requirements (spacecraft + instruments):

control = $\pm 1^\circ$

knowledge = $\pm 0.05^\circ$ (about 2.5 km)

stability = TBD

Instrument view angle = 82° (half-angle) cone about nadir for clear views of space and Earth

Instrument IFOV = approximately 3° diameter circle at the instrument centered about the optical axis [at nadir 25 to 35 km (polar platform) and about 15 km (Space Station), with about 1/50 sec between samples]; mirrors and solar attenuator plate sensitive to molecular and particulate contamination; protective measures integral to design.

Physical size = 1 m x 1 m x 1 m (for each of two packages)

Bruce Barkstrom, Principal Investigator

Bruce Barkstrom received a B.S. in physics from the University of Illinois. He received his 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 at the 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/ERL

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

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/NMC

V. Ramanathan, University of Chicago

G. Louis Smith, Langley Research Center

Larry L. Stowe, NOAA/NESDIS

Ronald Welch, Naval Oceanographic and Atmospheric Research Laboratory

Bruce A. Wielicki, Langley Research Center

David R. Brooks, Langley Research Center

Richard N. Green, Langley Research Center

Patrick Minnis, Langley Research Center

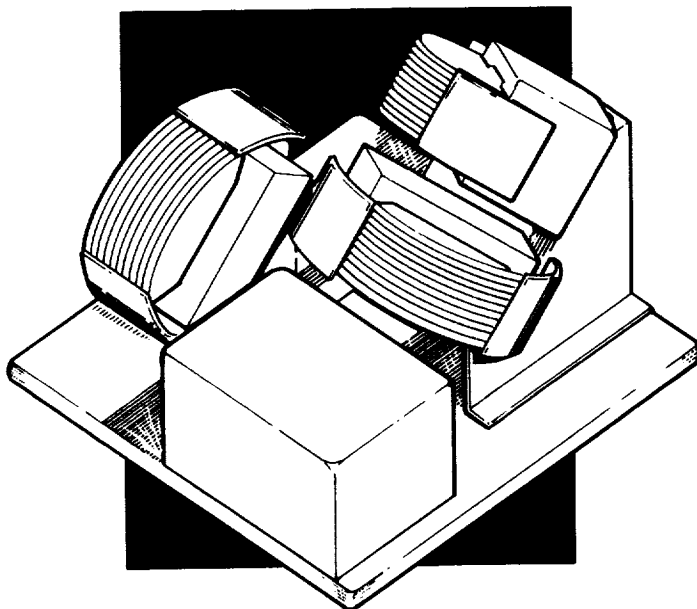
John T. Suttles, Langley Research Center

ENACEOS

Energetic Neutral Atom Camera for EOS

Using Energetic Neutral Atoms (ENAs) as an optical camera uses photons, the Energetic Neutral Atom Camera for EOS (ENACEOS) will obtain global "all sky" images of the global structure and dynamics of the Earth's magnetosphere. Also, *in situ* precipitating and trapped ion populations will be measured, providing detailed composition, spectral, and angular signatures over ranges corresponding to those of the remotely sensed ENA fluxes.

ENAs and ions are analyzed separately for energy (20 keV to several MeV), mass composition (H, He, CNO, etc.), and arrival directions ($3^\circ \times 3^\circ$ pixels). ENACEOS will provide for the first time global monitoring of the magnetosphere system and local measurements of ENA and ion atmospheric inputs, both critical inputs for quantifying magnetosphere/ionosphere/atmosphere coupling.



ENACEOS INSTRUMENT

- Energetic neutral atom camera
- Heritage: MEPA on Ampte CCE and EPIC on Geotail
- Globally monitors the magnetosphere system
- Three sensor heads; charge rejection plates discriminate between ions and ENAs
- Obtains spatial images of ENA sources with $3^\circ \times 3^\circ$ pixels

ENACEOS Parameters

Mass = 23 kg

Instrument duty cycle = 100%

Average power = Peak power = 16 W

Heater power = TBD (<5 W)

Passive thermal control

Thermal operating range = 23°C to 40°C

Average data rate = Peak data rate = 5 kbps

Pointing requirements (spacecraft):

control = 5°

knowledge = 0.5°

stability = N/A

Instrument view angle = 180° cross-track centered on zenith, 90° in-track centered on zenith

Instrument IFOV = 6° x 180°, 3° x 90°

Some sensitivity to direct exposure to attitude control jets.

Physical size = 50 cm x 50 cm x 50 cm

Barry H. Mauk, Principal Investigator

Barry Mauk received his B.A., M.S., and Ph.D. in physics from the University of California, San Diego. Following a research position at the University of Washington, where he was Co-Investigator on an x-ray imaging balloon program, Dr. Mauk joined the Applied Physics Laboratory of the Johns Hopkins University in 1982 as Senior Staff Physicist. His most recent activities include experimental and theoretical investigations of magnetospheric substorm injection and convection dynamics and of the interactions between electromagnetic cyclotron waves and heavy ions; the development of space instrumentation; and an additional role as Co-Investigator for operations and scientific investigations with the Voyager spacecraft, for which he was awarded a 1986 NASA Group Achievement Award.

Co-Investigators

Brian A. Tinsley, University of Texas, Richardson

Edwin P. Keath, Johns Hopkins University, APL

Richard W. McEntire, Johns Hopkins University, APL

Donald G. Mitchell, Johns Hopkins University, APL

Edmond C. Roelof, Johns Hopkins University, APL

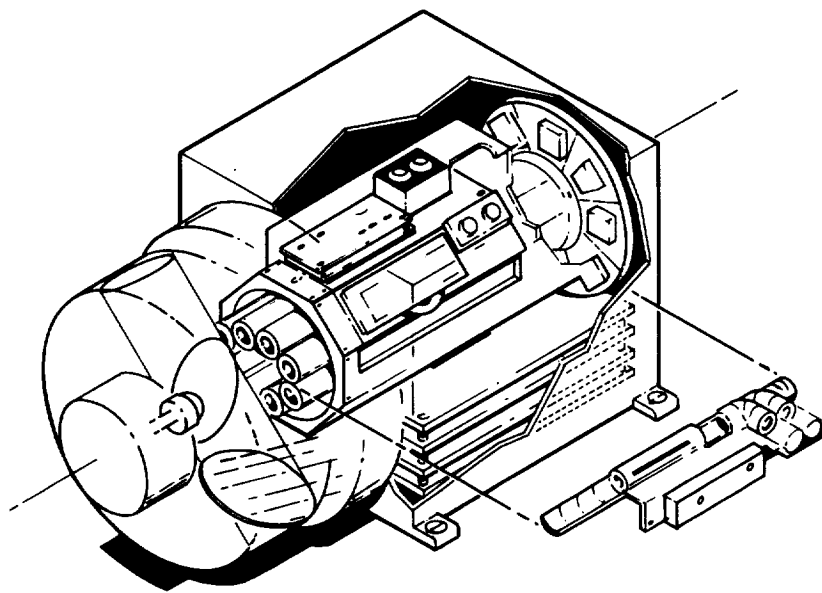
EOSP

Earth Observing Scanning Polarimeter

The EOSP will obtain global maps of the radiance and linear polarization of the reflected and scattered sunlight for 12 spectral bands in the visible and near-infrared. Analyses of these observations will permit the routine determination of cloud optical thickness, particle size and phase at the top of the cloud, and the pressure level of the cloudtop. These parameters constitute key information in quantifying the

radiative role of clouds and characterizing cloud feedbacks in global change. EOSP observations will also allow the determination of the distribution and optical thickness of aerosols, which in turn will be employed to provide estimates of radiance corrections that remove the effects of atmospheric scattering from other EOS observations of land and oceans.

CUTAWAY VIEW OF EOSP



- 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 cloud properties such as optical thickness and phase
- Provides global aerosol distribution

EOSP Parameters

Mass = 11 kg
Instrument duty cycle = 50% (powered on day side)
Average power = 12.4 W (day side); 0 W (night side)
Peak power = 17.5 W (calibration, 1% duty cycle)
Average data rate = 45 kbps
Peak data rate = 90 kbps (day side)
Thermal control by radiative cooler for cold focal plane
Thermal operating range = -40°C to 50°C
Pointing requirements (spacecraft + instrument):
 control = 1000 arcsec
 knowledge = 200 arcsec
 stability = 50 arcsec
Instrument view angle = $\pm 65^\circ$ from nadir, cross-track scan (limb to limb)
Instrument IFOV = 14.2 mrad (approximately 10 km at nadir)
Insensitive to expected contamination sources
Physical size = 22 cm (+ \pm 30 cm if solar diffuser assembly added) x 22 cm x 33 cm

Larry D. Travis, Principal Investigator

Larry D. Travis received his Ph.D. in 1971 from Pennsylvania State University. 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

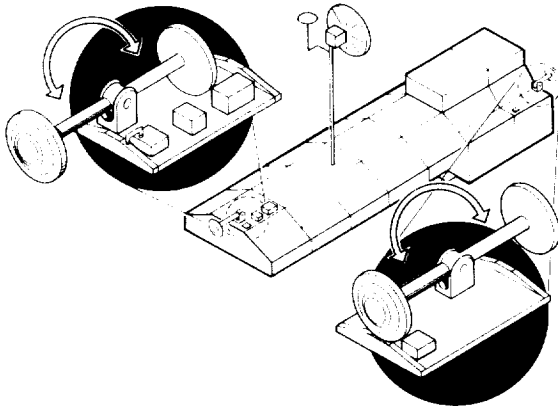
GGI

GPS Geoscience Instrument

GGI is a high-performance Global Positioning System (GPS) receiver-processor. It will include 18 dual-frequency satellite channels and three distributed GPS antennas. The antennas will be oriented to provide full-sky coverage down to the limb of the Earth for precise tracking and radio occultation measurements. GGI will serve four principal science objectives: centimeter-level global geodesy; high-precision atmospheric temperature profiling; ionospheric gravity wave detection and tomographic mapping; and precise positioning in support of other science instruments. Positioning capability will contribute to

developing centimeter-level global geodesy and enhanced altimetry accuracies from companion instruments. Occultation tracking will provide several hundred daily atmospheric temperature profiles to better than 0.5 K accuracy from 8 to 30 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 to be launched in 1992.

STRAWMAN GGI CONFIGURATION FOR POLAR PLATFORM



- GPS flight receiver-processor
- Heritage: GPS receiver on TOPEX/Poseidon
- Includes 18 dual-frequency satellite channels, 3 hemispherical pattern antennas, 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 centimeter-level global geodesy, high precision atmospheric temperature profiling, ionospheric gravity wave detection, and 3-D ionospheric tomography

GGI Parameters

Mass = 65 kg

Instrument duty cycle = 100%

Average power = Peak power = 90 W

Heater power = TBD (≤ 15 W)

Passive thermal control

Thermal operating range = 10° to 40°C

Average data rate = Peak data rate = 50 kbps

Pointing: The phase centers of the GGI antennas need to be known to 0.5 cm in platform coordinates

Instrument view angle = generally clear within cone 110° about zenith, two $\pm 70^\circ$ cones, one pointed forward on the spacecraft velocity vector and the other pointed aft on the negative velocity vector

No contamination sensitivity

Physical size:

electronics = 6" x 6" x 20"

each of 3 antennas = 4" diameter x 4" high cylinder on top of 14" diameter ground plane x 3" high cylinder

modules = 1.5 m x 2.0 m x 1.2 m and 1.5 m x 0.5 m x 1.0 m

William G. Melbourne, Principal Investigator

William Melbourne received his A.B. degree with highest honors in Astronomy-Physics from the University of California, Los Angeles, in 1954, and his Ph.D. degree in Astronomy from the California Institute of Technology in 1959. He joined the Jet Propulsion Laboratory 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 9 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

Lawrence E. Young, Jet Propulsion Laboratory

Thomas P. Yunck, Jet Propulsion Laboratory

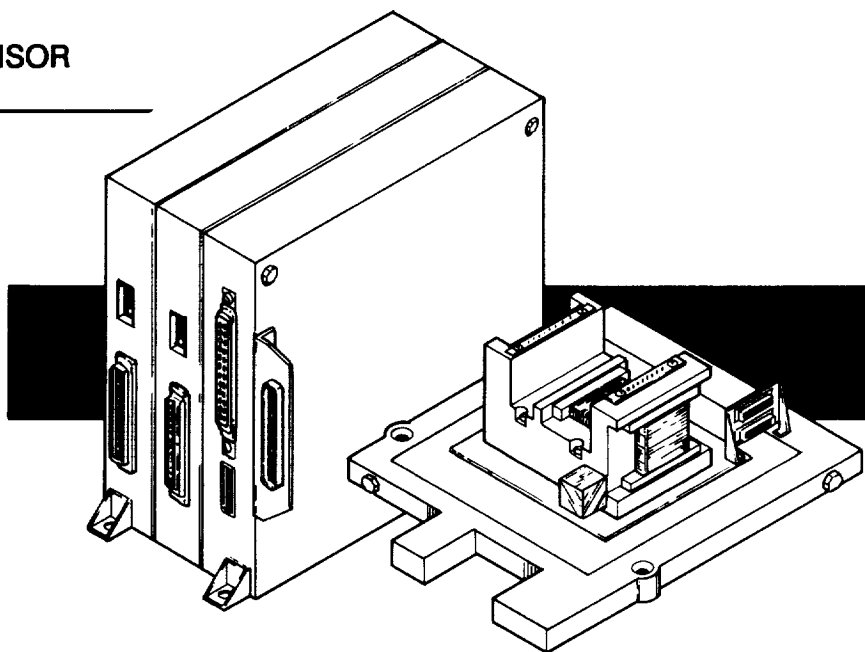
GOS

Geomagnetic Observing System

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. The team proposes specifically to: 1)

accurately model the magnetic field and its temporal change; 2) study core fluid dynamics; 3) study correlation with length-of-day changes; 4) study mantle conductivity; 5) measure characteristics and generation mechanisms of field-aligned and ionospheric currents; 6) Investigate dynamics and energetics of the high-latitude ionosphere; and 7) together with other spacecraft, do a multi-point investigation of the large-scale structure and dynamics of the auroral regions.

GOS VECTOR MAGNETOMETER SENSOR



- Boom-mounted vector fluxgate magnetometer; scalar-helium magnetometer
- Heritage: Magsat, ISEE-3/ICE
- Measures the Earth's magnetic field: obtains absolute scalar fields at \pm nanoteslas accuracy; vector fields at ± 3 nanoteslas per axis, rss
- Two orthogonal scalar magnetometers/tri-axial vector magnetometer mounted at end of 50-m boom
- Three star trackers provide pointing knowledge

GOS Parameters

Mass = 140 kg
Instrument duty cycle = 100%
Average power = Peak power = 120 W
Heater power = TBD (≤ 35 w)
Thermal control is active and passive,
Average data rate = Peak data rate = 16 kbps
Pointing requirements (Instrument star cameras):
 control = 20 arcsec; knowledge = TBD; stability = TBD
Instrument view angle = 10° for each of 3 star cameras fields
Negligible sensitivity to outgassing contamination, but sensitive to magnetic fields
Physical size: boom canister = 1.5' to diameter x ~2' high
 platform at end of boom = 2' x 2'
Note: Power, telemetry, and command are not redundant.

Robert Langel III, Principal Investigator

Dr. Langel has studied the Earth's magnetic field since the mid-1960s. He has pioneered in the development of magnetic field modeling methods and has written a definitive work on main-field modeling. His Ph.D. degree is in physics and he has been associated with Goddard Space Flight Center since 1963, from 1975 with the Geophysics Branch, Laboratory for Terrestrial Physics. He was part of the magnetometer team for the POGO spacecraft, was project scientist for Magsat, and is NASA study scientist for MFE/Magnolia. He was recipient of the NASA Exceptional Scientific Achievement Medal, Visiting Scholar at Cambridge University in 1983-84, and is a recently elected 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
David R. Barraclough, British Geological Survey
Edward R. Benton, University of Colorado
Peter F. Bythrow, Johns Hopkins University
Yahsuke Kamide, Kyoto Sangyo University
George E. Backus, University of California, San Diego
Jean Louis LeMouel, Institut de Physique du Globe de Paris
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Thomas A. Potemra, Johns Hopkins University
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Edward J. Smith, Jet Propulsion Laboratory
Masahisa Sugiura, Geophysical Institute
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Takeshi Yukutake, University of Tokyo
Lawrence J. Zanetti, John Hopkins University
Coerte Voorhies, Goddard Space Flight Center
Karl-Heinz Glassmeier, Universitat Koln

HIMSS

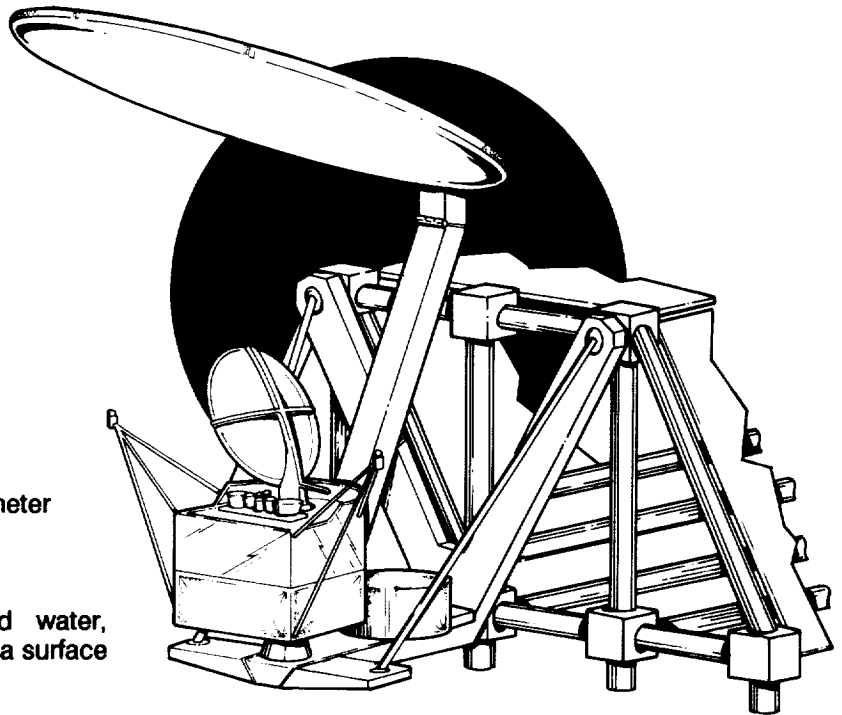
High-Resolution Microwave Spectrometer Sounder

The High-Resolution Microwave Spectrometer Sounder (HIMSS) will be used for the retrieval of numerous atmospheric and oceanic parameters, including precipitation rates over both land and ocean in multiple layers, oceanic cloud water and water vapor content, wind speed and sea surface temperatures, atmospheric temperature profile, snow cover depth and water equivalent, and possibly vegetation. This instrument will build upon the successful heritage

of the Special Sensor Microwave/Imager (SSM/I), with special emphasis on instrument design that provides: (1) an accurate and stable calibration design to allow meaningful monitoring of Earth and atmospheric processes on time scales of many years, (2) swath width improved over current microwave radiometers, (3) order-of-magnitude improvement in footprint areal resolution, (4) high radiometric sensitivity, and (5) co-located footprints.

HIMSS VIEWING GEOMETRY, POLAR PLATFORM

- High-resolution microwave spectrometer
- Heritage: SSM/I
- Measures precipitation rate, cloud water, water vapor, temperature profiles, sea surface roughness, SST, ice, and snow
- Frequencies between 6.6 and 90 GHz
- 2 m parabolic antenna and rotating drum at 40 rpm



HIMSS Parameters

Mass = 204 kg (including payload support structure)
Instrument duty cycle = 100%
Average power = 126 W
Peak power = 200 W (start-up only)
Heater power = 60 W
Thermal control by passive cooling and active heating
Thermal operating range = -4°C to 40°C
Average data rate = Peak data rate = 44 kbps
Pointing requirements (spacecraft):
 control = 360 arcsec
 knowledge = 180 arcsec
 stability = 90 arcsec
Instrument view angle = cone 46° around nadir, 140° swath centered on satellite subtrack
Instrument IFOV (major axis) = 5 km at 90 GHz to 50 km at 6.6 GHz
No contamination sensitivity
Physical size = 2 m x 2 m x 2 m

Roy W. Spencer, Principal Investigator

Roy W. Spencer received his 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 data analysis from the DMSP SSM/I, the Nimbus-7 SMMR, and the MOS-1 MSR; 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 Science Steering Group, the Earth Science Geostationary Platform Committee, and the Earth System Science Subcommittee on Winds and Precipitation.

Co-Investigators

Al Chang, Goddard Space Flight Center
Louis Dod, Goddard Space Flight Center
Elena Lobl, Hughes Aircraft Company
Gerald North, Texas A&M University
James Shiue, Goddard Space Flight Center
Joanne Simpson, Goddard Space Flight Center
David Staelin, Massachusetts Institute of Technology
James Wang, Goddard Space Flight Center
Frank J. Wentz, Remote Sensing Systems
Tom Wilhelm, Texas A&M University

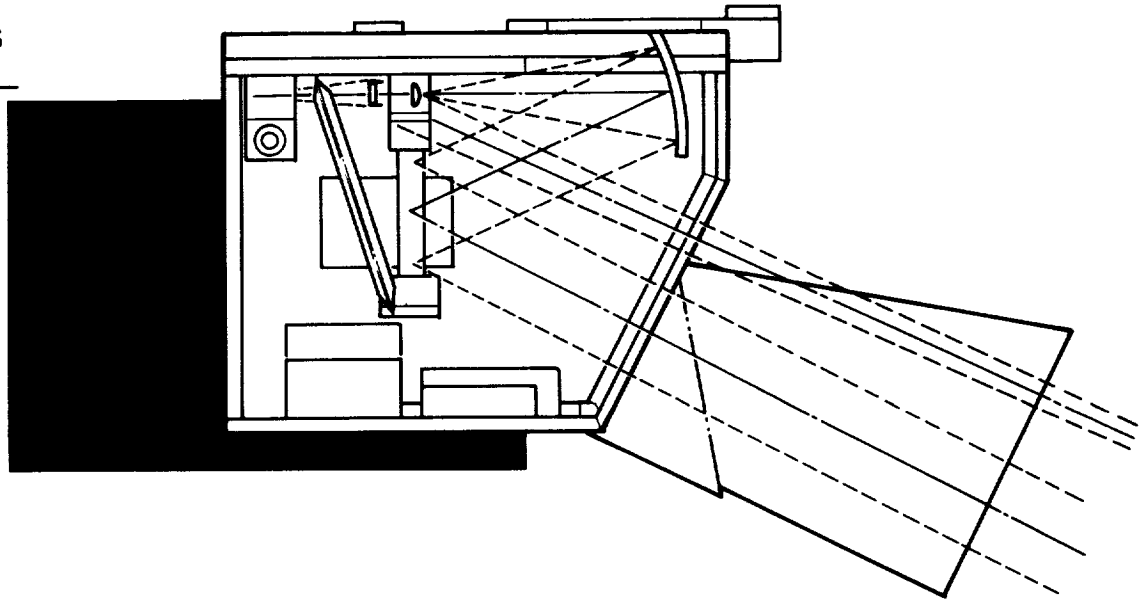
HIRDLS

High-Resolution Dynamics Limb Sounder

HIRDLS is an infrared limb scanning radiometer designed to sound the upper troposphere, stratosphere, and mesosphere to determine temperature and the concentrations of O_3 , H_2O , CH_4 , N_2O , NO_2 , HNO_3 , N_2O_5 , CFC_{11} , CFC_{12} , and aerosols. 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-dimensional models. 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 by the use of special narrow and more transparent spectral channels. The instrument is programmable, thus a variety of observation modes can be used, and these adapted in flight to observe unexpected geophysical events.

HIRDLS



- 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} , and aerosols in the upper troposphere, stratosphere, and mesosphere
- Spectral range 6 to 18 micron
- Profile spacing 4° longitude x 4° latitude; 1-km vertical resolution
- Fore-optics based on UARS ISAMS and focal plane based on Nimbus-7 LIMS, other heritage Nimbus-4, 5, 6 and UARS
- Instrument characteristics and measurement parameters are listed in the Appendix

HiRDLS Parameters

Mass = 150 kg
Instrument duty cycle = 100%
Average power = Peak power = 150 W
Heater power = TBD
Thermal control by cooling loop (could use passive radiators, but these would require cold space view)
Thermal operating range = 15°C to 35°C, requires stable cooling plate temperatures over orbital periods
Average data rate = Peak data rate = 15 kbps
Pointing requirements (Instrument + spacecraft):
 control = 100 arcsec (3 sigma)
 knowledge = 100 arcsec (3 sigma)
 stability = 1 arcsec per second (3 sigma, spacecraft only)
Instrument view angle = azimuth 90° on +y side to 25° on -y side; elevation 22-27° below x-y plane rearward
Instrument IFOV = 1-2 km x 10 km
Medium contamination sensitivity. Aperture doors will be used for launch.
Physical size = about 1 m x 1 m x 1 m

John Barnett, Co-Principal Investigator

Dr. Barnett received his M.A. in natural sciences, with first class honors, from Cambridge University and his Ph.D. in atmospheric physics from Oxford University. He is currently a University Research Lecturer for the Department of Atmospheric, Oceanic, and Planetary 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, Co-Principal Investigator

John Gille received his B.S. in physics, magna cum laude, from Yale University; his M.A. in physics from Cambridge University; and the 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, Hooke Institute for Atmospheric Research
Byron Boville, National Center for Atmospheric Research
Guy Brasseur, National Center for Atmospheric Research
Michael Coffey, National Center for Atmospheric Research
Allen Cox, Honeywell Corporation
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. Mueller, University of Sheffield

Christopher T. Mutlow, Rutherford Appleton Laboratory
Alan O'Neill, British Meteorological Office
Guy D. Peskett, Oxford University
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

IPEI

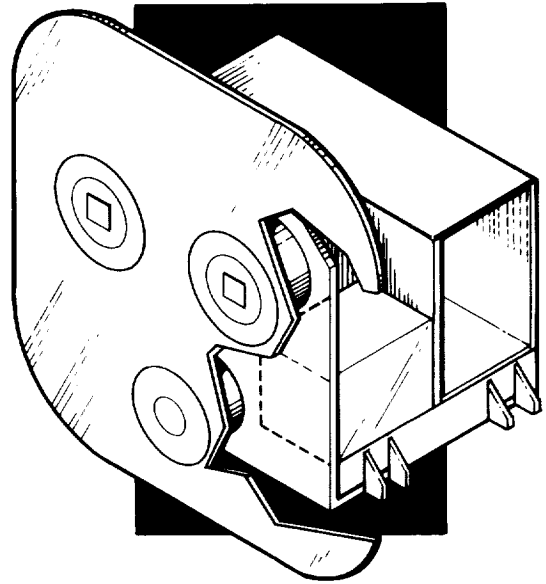
Ionospheric Plasma and Electrodynamics Instrument

The Ionospheric Plasma and Electrodynamics Instrument (IPEI) will measure thermal ion and electron temperatures, ion composition, and the ion dynamics in ionosphere. These measurements serve as remote sensors of the electric fields generated in the lower atmosphere by motions of the charged and neutral particles and electric fields generated by the interaction of the Earth with the interplanetary environment. The measurements will also monitor the energy transport and conversion processes that take place as a result of interactions with the lower

atmosphere and the upper atmosphere. When used in conjunction with energetic particle and magnetometer data, the energy input to the lower atmosphere can be expressed as a Poynting flux. Questions pertaining to thermal ion supply to the magnetosphere, the characteristics of the high-latitude electric field and associated frictional heating, the roles of neutral atmosphere motions near 120-km altitude, and the effects of propagating gravity waves will also be addressed with data from IPEI.

IPEI INSTRUMENT

- Retarding potential mass analyzer (RPMA) and ion drift meter (IDM)
- Heritage: Atmosphere Explorer and Dynamics Explorer
- Determines thermal energy distribution and thermal ion arrival angle with respect to spacecraft velocity
- Determines relative abundance of ionospheric constituents H⁺, He⁺, O⁺
- Ion drift is measured from 10 to 5,000 m/s in 3 directions, concentrations from $1.5 \times 10^8 \text{ cm}^{-3}$, and temperatures from 200 to 20,000 K



IPEI Parameters

Mass = 11 kg

Instrument duty cycle = 100%

Average power = Peak power = 10 W

Heater power = small, TBD

Thermal control by electric heater and passive radiator

Thermal operating range = -10°C to 50°C

Average data rate = Peak data rate = 1.1 kbps

Pointing requirements (spacecraft):

control = 0.5°

knowledge = 0.1°

stability = <0.1° per second

Instrument view angle = Instrument IFOV = 45° cone around spacecraft velocity vector

Insensitive to expected contamination sources

Physical size = 10" x 10" x 9" with a 16" x 16" x 0.125" ground plane at one end

Roderick Heelis, Principal Investigator

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 16 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, in addition, is a past Associate Editor of the *Journal of Geophysical Research* and the recipient of that Journal'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, Dallas

John H. Hoffman, University of Texas, Dallas

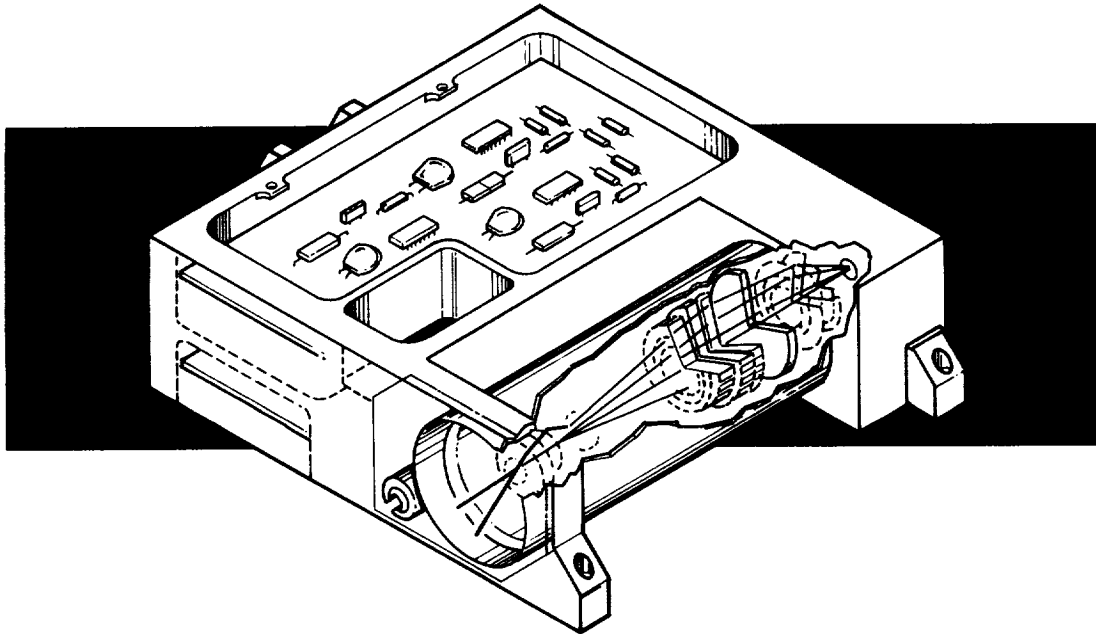
LIS

Lightning Imaging Sensor

The calibrated optical Lightning Imaging Sensor (LIS) will acquire and investigate the distribution and variability of lightning over the Earth. LIS is conceptually a simple device, consisting of a staring imager optimized to detect and locate both intracloud and cloud-to-ground lightning with storm-scale resolution over a large region of the Earth's surface, mark the time of occurrence, and measure the radiant energy. It will monitor individual storms within the field-of-view for 2

minutes, long enough to estimate the lightning flashing rate. 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 and to the release and transport of latent heat. LIS is also being developed for flight on the manned Space Station.

LIS - LIGHTNING IMAGING SENSOR



- Staring telescope/filter imaging system
- Under development for geostationary orbit; flown on NASA U.S. 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 ms temporal resolution

LIS Parameters (Polar Platform and Space Station)

Mass = 7.5 kg
Instrument duty cycle = 100%
Average power = Peak power = 15 W
Heater power =
Thermal control by passive radiators
Thermal operating range
Average data rate = 500 bps
Peak data rate =
Pointing requirements (Instrument + spacecraft):
 control =
 knowledge = 293 arcsec (1 km on the ground)
 stability = 1000 arcsec per second
Instrument view angle = instrument IFOV = 75° cone around nadir
Negligible contamination sensitivity
Physical size = 12" x 10" x 4"

Hugh Christian, Principal Investigator

Hugh Christian is a graduate of the University of Alaska and received his M.S. and Ph.D. degrees 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

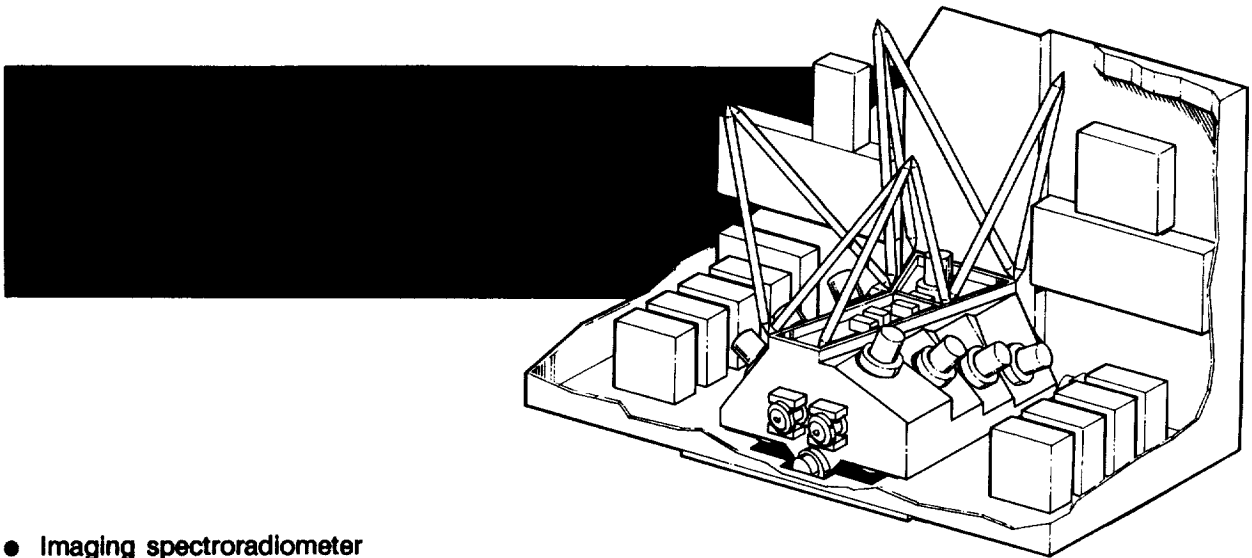
MISR

Multi-Angle Imaging Spectro-Radiometer

The MISR instrument will obtain continuous multi-angle imagery of the Earth through the use of eight separate CCD-based pushbroom cameras, each operating at wavelengths of 440, 550, 670, and 860 nm. This experiment addresses the effects of geophysical processes and human activities on the Earth's ecology and climate. Scientific research areas that will utilize MISR data 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. Standard MISR data products will include top-of-atmosphere, cloud, and surface angular reflectance functions classified by scene type, and global maps (produced every 16 days) of planetary and surface albedo; aerosol opacity, absorptivity, and loading; vegetation index; and phytoplankton pigment concentration in the tropical oceans. 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 on-board hardware. Validation of MISR data products will result from field campaigns coordinated with other EOS investigations.

THE MISR INSTRUMENT



- Imaging spectroradiometer
- Heritage: Galileo, Wide-field/Planetary Camera
- Provide top-of-atmosphere, cloud, and surface angular reflectance functions
- Provide global maps of planetary and surface albedo, and aerosol and vegetation properties

MISR Parameters

Mass = 85 kg

Instrument duty cycle = 100%

Average power = 47 W (70 W data taking, 61% duty cycle)

Peak power = 95 W (calibration)

Heater power = 20 W

Thermal control by passive cooling and active temperature stabilization

Thermal operating range = -20°C to 40°C

Average data rate = 70 kbps (140 kbps day side, global mode: 99% of data taking)

Peak data rate = 3.6 Mbps (day side, local mode: 1% of data taking)

Pointing requirements (spacecraft):

control = 230 arcsec

knowledge = 90 arcsec

stability = 1 arcsec per second, 6 arcsec per 420 seconds

Instrument view angle at Earth's surface = -72.5°, -60.0°, -45.6°, -25.8°, 0.0, 36.9°, 53.1°, 66.4° (in-track from nadir)

Instrument IFOV:

swath width = 408 km (normally edited to 204 km)

spatial resolution = 1.92 km for global coverage (global mode)

= 240 m for regional coverage of selected targets (local mode)

Contamination sensitivity is low. Protective measures are integral to design.

Physical size = 53" x 28" x 20"

David J. Diner, Principal Investigator

David J. Diner received his B.S. in physics with honors from the State University of New York at Stony Brook, and his 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 a member of the American Astronomical Society Division for Planetary Sciences and a member of the NASA Land Aircraft Science Management Operations Working Group.

Co-Investigators

John V. Martonchik, Jet Propulsion Laboratory

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

Piers Sellers, University of Maryland

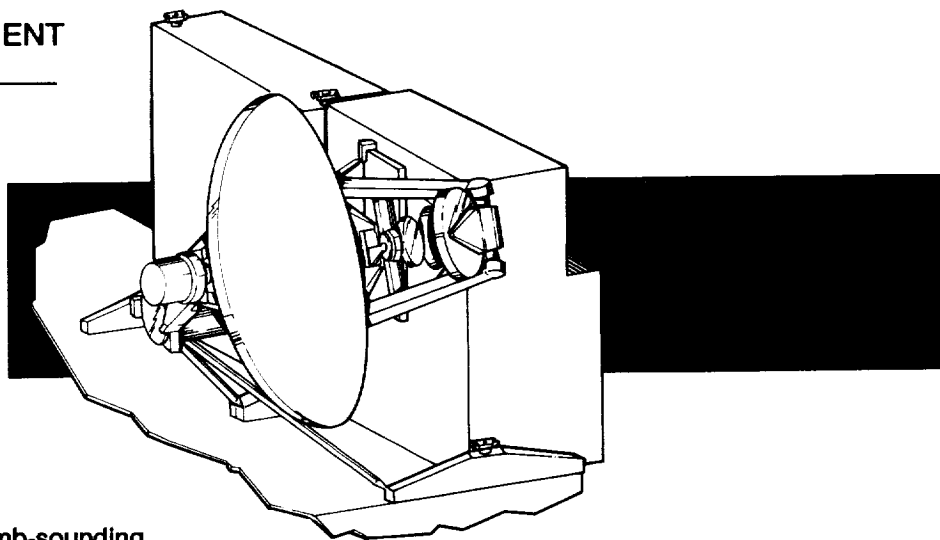
MLS

Microwave Limb Sounder

The MLS investigation will study and monitor atmospheric processes that govern stratospheric and mesospheric ozone. Emphasis is on chlorine 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 which 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, including in the presence of polar stratospheric clouds. A vertical scan covering 0 to 120 km tangent heights in 2.5 km steps will be made each 2.5° along the orbit. Data products include vertical profiles of O₃, ClO, HCl, HOCl, OCIO, CH₂Cl, BrO, HO₂, H₂O₂, H₂O, NO, NO₂, N₂O, HNO₃, CO, H₂CO, HCN, SO₂, O₂, temperature, pressure, one component of mesospheric wind, and liquid water near the tropopause.

THE MLS INSTRUMENT



- Passive 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 637, 560, 205, 117, and 270 (or 63) GHz
- Spectral resolution: 0.01-1 MHz ($0.3 - 3 \times 10^{-5} \text{ cm}^{-1}$)
- Instantaneous field-of-view at 637 GHz: 1.2 km vertical x ~300 km along-track x 3 km cross-track at the limb tangent point
- Instrument characteristics and measurement parameters are detailed in the Appendix

MLS Parameters

Mass = 450 kg

Instrument duty cycle = 100%

Average power = 650 W (to simultaneously perform all measurements; power can be reduced, if necessary, by time-sharing some measurements)

Peak power = 900 W ($\leq 5\%$ duty cycle as power available)

Heater power = ≤ 50 W (needed only when instrument off)

Thermal control is radiational (need space view away from sun)

Average data rate = Peak data rate = 1 Mbps

Pointing requirements (spacecraft + instrument):

control = 1800 arcsec

knowledge = 180 arcsec

stability = 10 arcsec per second, all axes

Instrument view angle = towards atmospheric limb

Instrument IFOV = 0.025° vertical (1.2 km at limb)

Negligible contamination sensitivity

Physical size:

antenna = 1.6 m x 0.8

modules = 1.5 m x 2.0 m x 1.2 m and 1.5 m x 0.5 m x 1.0 m

Joe W. Waters, Principal Investigator

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 to JPL in 1973 and has been Principal Investigator on aircraft, balloon, and UARS microwave limb sounding experiments. He is currently 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

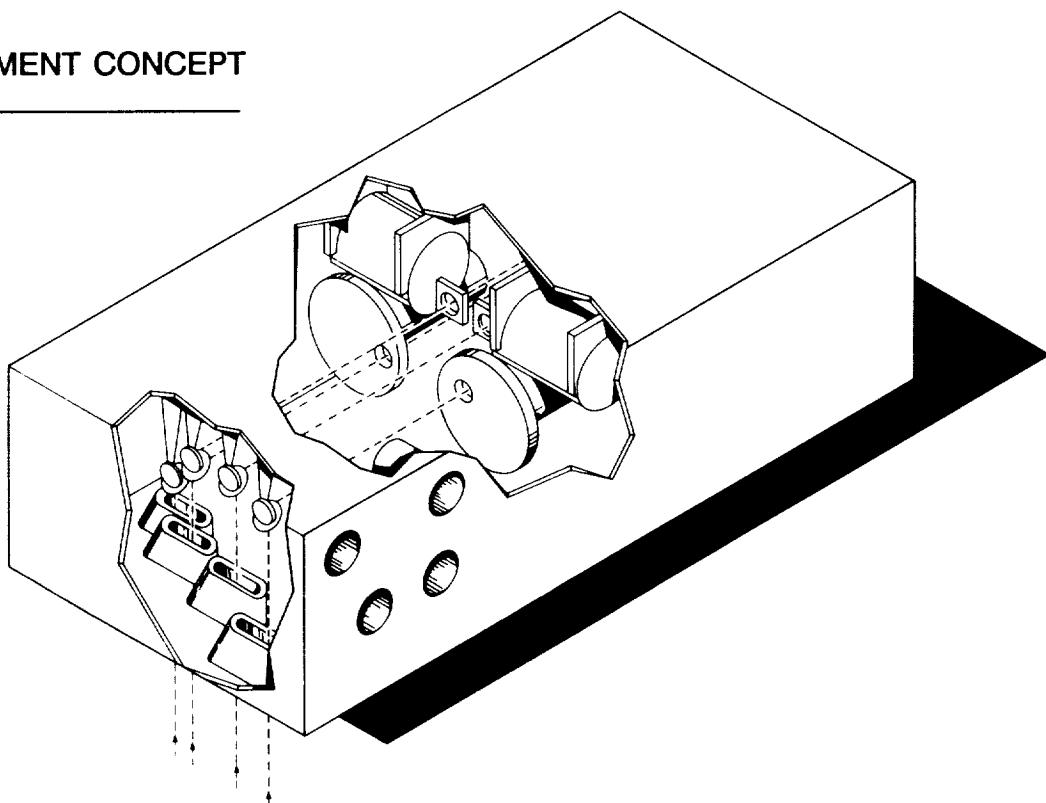
MOPITT

Measurements of Pollution in the Troposphere

The Measurements of Pollution in the Troposphere (MOPITT) experiment will measure carbon monoxide (CO) concentrations in the troposphere with the primary objective of enhancing knowledge of the lower atmosphere system and particularly how it interacts with the surface, ocean, and biomass systems. The investigation uses a radiometer instrument that operates by sensing upwelling infrared radiation

in several bands of CO. As well as measuring the total amount of CO, profiles with a resolution of 22 km horizontally, 3 km vertically and with an accuracy of 10% will be obtained throughout the troposphere. Global 3-D maps will be constructed and used in a parallel modeling effort to advance understanding of global tropospheric chemistry.

MOPITT INSTRUMENT CONCEPT



- Four-channel correlation spectrometer with cross-track scanning
- Heritage: uses PMC elements used in the PMR, SAMS, and ISAMS instruments and uses similar correlation spectroscopy techniques
- Measures upwelling radiance in the CO bands at $2,140\text{ cm}^{-1}$ and $4,100\text{ cm}^{-1}$
- Uses pressure modulation and length modulation cells to obtain CO concentrations in 3-km layers

MOPITT Parameters

Mass = 73 kg
Instrument duty cycle = 100%
Average power = Peak power = 182 W
Heater power = TBD
Thermal control by stirling-cycle cooler and platform cooling loop
Thermal operating range = TBD
Average data rate = Peak data rate = 1 kbps
Pointing requirements (spacecraft):
 control = 300 arcsec
 knowledge = 300 arcsec
 stability = 300 arcsec
Instrument view angle (from nadir) = rectangle $\pm 3.6^\circ$ in-track by $\pm 25^\circ$ cross-track
Instrument FOV = $\pm 3.6^\circ$ in-track by $\pm 0.9^\circ$ cross-track
Insensitive to expected contamination sources
Physical size = 0.48 x 0.63 x 0.41 m

James Drummond, Principal Investigator

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 NCAR in 1987. His research interests are in the field of atmospheric measurements and modeling, and he has participated in several balloon and spacecraft experiments. Dr. Drummond has presented research papers at international meetings and symposia, and in refereed journals.

Co-Investigators

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

POEMS

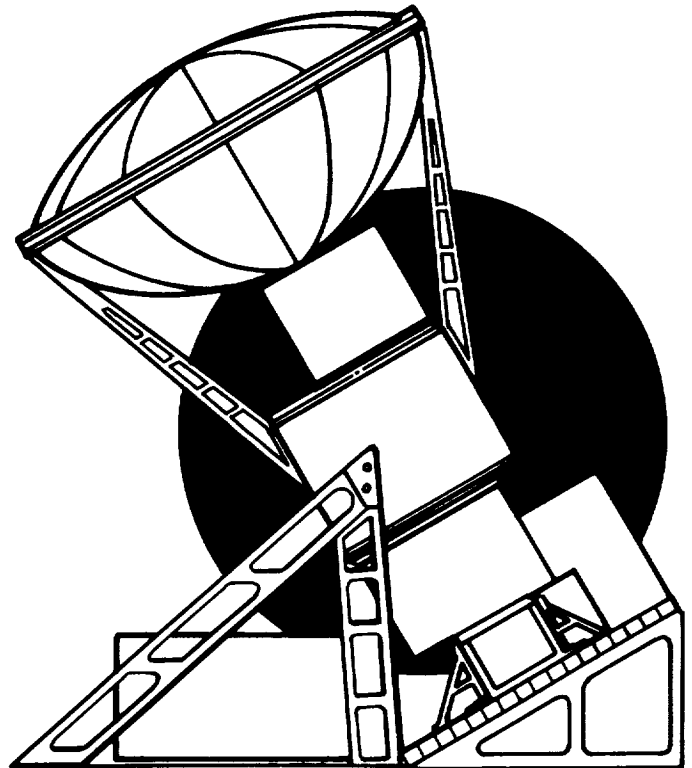
POsitrion Electron Magnet Spectrometer

POEMS (POsitrion Electron Magnet Spectrometer) is an energetic particle detector designed to take advantage of the unique orbit and mission duration provided by the EOS polar platform(s) to do fundamental research in the area of particle astrophysics and at the same time study the nature and the temporal variation of the charged particle radiation in near-Earth space. POEMS will measure the critical positron (e^+) and electron (e^-) components of the cosmic radiation in the energy range 5 MeV to 5 GeV. Additionally, POEMS will provide spectra of protons, helium, and heavier nuclei at energies ranging from 20 MeV/nucleon to 20 GeV/nucleon as well as spectra of solar flare

gamma-rays and neutrons. Data from POEMS will allow detection of a possible primary component of galactic positrons, study of the charge sign dependence of solar modulation over a large portion of a solar magnetic cycle, and measurement of the positron abundance in solar flare particles. Particle data from POEMS will be converted into a complete, daily, 3-D, global map of the input of ionizing radiation into the atmosphere at altitudes below 30 km for use in efforts to determine the influence of such radiation on physical processes such as cloud formation and on the chemistry of trace components.

POEMS MOUNTED ON ZENITH SURFACE OF EOS POLAR PLATFORM

- Magnet spectrometer
- Heritage: balloon instruments and OGO; ISEE/ICE spacecraft
- Measures positrons and electrons in 5 MeV to 5 GeV range
- Provides spectra of protons, helium, and heavier nuclei in 20 MeV/nucleon to 20 GeV/nucleon range



POEMS Parameters

Mass = 125 kg
Instrument duty cycle = 100%
Average power = Peak power = 110 W
Heater power = TBD
Passive thermal control
Thermal operating range = 0° to 20°C
Average data rate = 13 kbps
Peak data rate = 600 kbps (~0.5 day during intense solar events)
Point requirements:
 control = $\pm 3^\circ$
 knowledge = $\pm 3^\circ$
Instrument view angle = 20° cone around 30° from zenith and 20° cone around 60° from zenith
Low sensitivity to expected contaminant environment
Physical size = 75 cm x 75 cm x 75 cm (outside dimensions)

Note: No internal mechanical motions; Zenith mounting required.

Paul A. Evenson, Principal Investigator

Paul Evenson received his B.A., M.A., and Ph.D. in physics from the University of Chicago, where he also served as Research Associate and Senior Research Associate in the Enrico Fermi Institute. He has been honored as a National Science Foundation Graduate Fellow, a NATO Fellow at the Danish Space Research Institute, Guest Scientist at the Max-Planck Institute for Extraterrestrial Studies, and as recipient of the NASA Group Achievement award. Currently, Dr. Evenson is Associate Professor at the University of Delaware Bartol Research Institute.

Co-Investigators

Louis Barbier, Goddard Space Flight Center
T. Gregory Guzik, Louisiana State University
Karen Magee-Sauer, University of Delaware
John Mitchell, Louisiana State University
Jonathan F. Ormes, Goddard Space Flight Center
Reuven Ramaty, Goddard Space Flight Center
Donald Reames, Goddard Space Flight Center
Michael Salamon, University of Utah
Robert Streitmatter, Goddard Space Flight Center
Simon Swordy, University of Chicago
John P. Wefel, Louisiana State University

SAFIRE

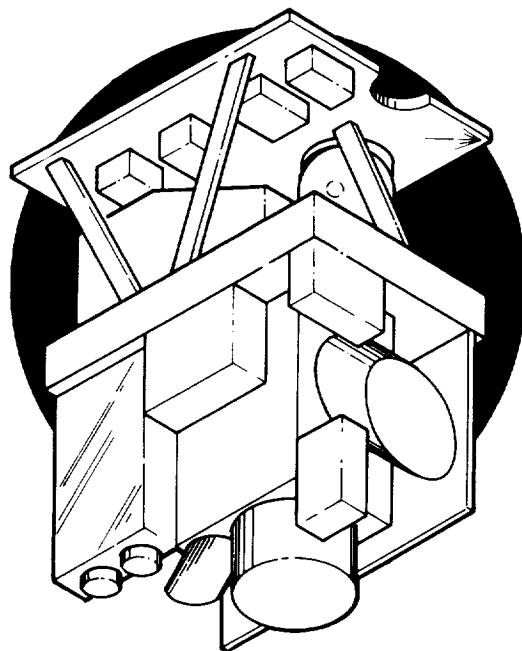
Spectroscopy of the Atmosphere Using Far Infrared Emission

The goal of the Spectroscopy of the Atmosphere using Far Infrared Emission (SAFIRE) experiment is to achieve improvement in our 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 experiment that combines the advantages of far-IR Fourier transform spectroscopy and space-proven mid-IR broadband-radiometry. The experiment brings together simultaneous observations by one instrument of key HOy, NOy, ClOy, and BrOy gases, coupled with dynamical tracer measurements including vertical profiles of temperature, O₃, O₃⁵⁰, O(³P), OH, HO₂, H₂O₂,

H₂O, HDO, CH₄, NO₂, HNO₃, N₂O₅, HCl, HOCl, HBr, and HF. Some important applications of the data include the study of: (1) major processes in the main chemical families, (2) polar night chemistry, (3) non-local thermodynamic equilibrium, (4) diurnal changes in key gases, (5) dynamics and transport processes, (6) chemistry and dynamics coupling, and (7) lower stratospheric phenomena. SAFIRE will directly address seven major EOS scientific objectives, make essential contributions in the study of natural and human-induced changes and three science priorities identified in the CES 1989 report, and make significant contributions in four others.

SAFIRE INSTRUMENT MOCK-UP

- Seven-channel far-IR Fourier transform spectrometer (0.004 cm⁻¹ spectral resolution) and seven-channel mid-IR broadband LIMS-type radiometer
- Heritage: LRIR, LIMS, SAMS, ATMOS
- Globally measures chemical, radiative, and dynamical processes which 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)
- Instrument characteristics and measurement parameters are detailed in the Appendix.



SAFIRE Parameters

Mass = 304 kg

Instrument duty cycle = 100%

Average power = Peak power = 304 W

Liquid He (4 K) cooling in far-IR and mechanical refrigerator (80 K) cooling in mid-IR

Average data rate = Peak data rate = 9 Mbps

Pointing requirements (spacecraft):

control = 3600 arcsec

knowledge = not needed

stability = 5 to 15 arcsec

Instrument view angle = 1° x 1° square swept over depression angle of 17° to 29°, 15° off-track

Instrument IFOV = 3 km (vertical far-IR), 1.5 km (vertical mid-IR)

Contamination sensitivity: low instrument noise requires high off-axis rejection optical system

Physical size = 1.4 m x 1.6 m x 1.6 m

Note: Self-contained pointing subsystem based on use of two mid-IR CO₂ channels. Experiment uses four scan modes depending on science objective: chemistry, polar chemistry, dynamics, and thermospheric modes.

James M. Russell III, Principal Investigator

Dr. Russell received his 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 Spacelab 3 ATMOS experiment, launched on Shuttle in 1985; and he is Principal Investigator on HALOE and Co-Investigator on ISAMS scheduled to fly on UARS in 1991. He has been a Visiting Scientist at NCAR, is listed in several biographical periodicals which 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, Duke 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, University of Cambridge
Ellis E. Remsberg, Langley Research Center
Clive D. Rodgers, Oxford University
Susan Solomon, NOAA/ERL
Adrian F. Tuck, NOAA/ERL

SAGE III

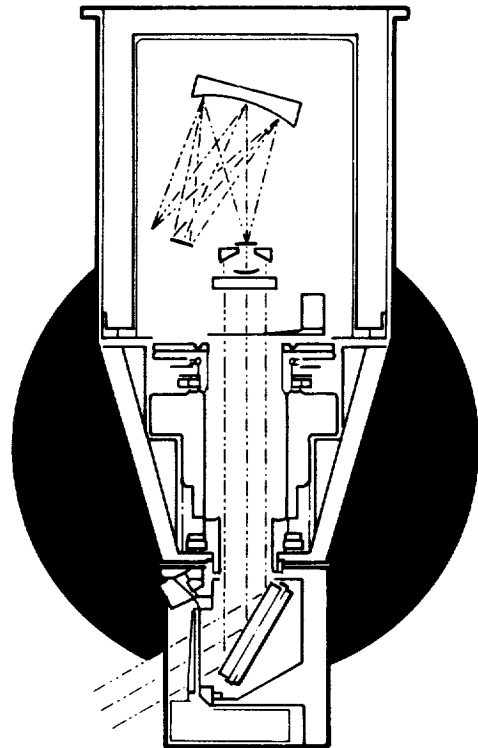
Stratospheric Aerosol and Gas Experiment III

The Stratospheric Aerosol and Gas Experiment III (SAGE III) will measure profiles of aerosols, O_3 , NO_2 , NO_3 , H_2O , and air density 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 SAM II, SAGE I, and SAGE II experiments, and will include additional wavelengths and lunar occultation to accomplish the following: (1) improve aerosol characterization; (2) improve the gaseous retrievals of O_3 , H_2O , NO_2 , NO_3 ; (3)

extend the vertical range of measurement; and (4) provide total self-calibration independence from any external data needed for retrieval. SAGE III will be capable of making long-term band measurements and will provide aerosol and cloud data important to radiative and atmospheric chemistry studies, and essential for the calibration and interpretation of data from other remote sensors on the EOS platforms. SAGE III is also planned for flight on the manned Space Station.

SAGE III SENSOR ASSEMBLY

- Earth-limb scanning grating spectrometer
- Heritage: SAM II, SAGE I, SAGE II
- Obtains global profiles of aerosols, O_3 , H_2O , NO_2 , NO_3 , clouds and air density in the mesosphere, stratosphere, and troposphere
- 1- to 2-km vertical resolution
- Instrument characteristics and measurement parameters are detailed in the Appendix



SAGE III Parameters

Mass = 30.0 kg

Instrument duty cycle = 20%

Average power = 5 W (30 W for 16 min each orbit)

Heater power = 5 W (average), 15 W (peak)

Peak power = 45 W (transient, twice per orbit)

Thermal control by active heating and passive cooling

Thermal operating range = 5 to 35°C

Average data rate = 15 kbps

Peak data rate = 82 kbps (data taking)

Pointing requirements (spacecraft):

control = $\pm 0.5^\circ$; knowledge = $\pm 0.5^\circ$; stability = 30 arcsec per second

Instrument view angle = $24.4^\circ \pm 3^\circ$ (NPOP-1) or $17.4^\circ \pm 5.6^\circ$ (space station)

IFOV = 30 arcsec elevation (approximately 0.5 km)

Molecular and particulate contamination not expected to be a problem.

Physical size: 13" dia x 29" high cylinder and 13" x 7.5" x 7"

M. Patrick McCormick, Principal Investigator

M. Patrick McCormick received his 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, and SAGE II spaceflight experiments as well as numerous other atmospheric remote sensing instruments 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, and numerous NASA Group or Special Achievement Awards. 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 and chairs the International Coordination Group on Laser Atmospheric Studies.

Co-Investigators

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Geoffrey Kent, Science & Technology Corporation

Jacqueline Lenoble, Université des Sciences et Techniques de Lille

Alvin J. Miller, NOAA/NMC

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Venkatachalam Ramaswamy, Princeton University

David H. Rind, Goddard Institute for Space Studies

Philip B. Russell, Ames Research Center

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Eric Shettle, Air Force Geophysics Laboratory

Gabor Vall, University of Wyoming

Steven Wofsy, Harvard University

Joseph M. Zawodny, Langley Research Center

SCANSCAT/STIKSCAT

Scatterometers are active microwave radars designed specifically to acquire all-weather measurements of surface wind speed and direction over the global oceans. Based on Seasat and NSCAT heritage, accuracies of 10% in speed and 20 degrees in direction are possible at a spatial resolution of 25 km.

Both the classical fan-beam (STIKSCAT) and advanced dual pencil-beam (SCANSCAT) scatterometer designs are being considered for EOS. STIKSCAT will acquire data in two, 550-km swaths separated by a 325-km gap at nadir,

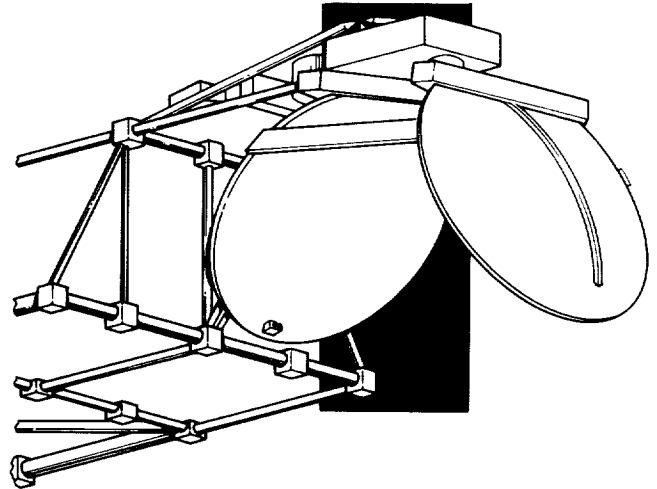
resulting in daily coverage of 76% of the ice-free oceans. SCANSCAT will have a single, continuous 1,600-km wide swath, with daily coverage of 98% of the oceans and increased accuracy at low wind speeds.

The wind velocity data from scatterometers will be used for calculating all air-sea fluxes, modeling upper-ocean circulation and tropospheric dynamics, and improving global weather prediction. Vector wind and wind stress data at high resolution, as well as spatial/temporal average maps will be available as standard products.

SCANSCAT/STIKSCAT

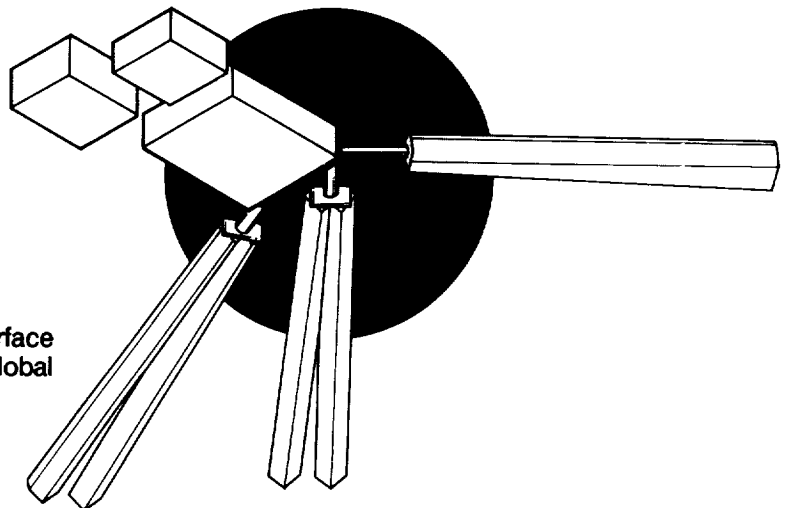
SCANSCAT:

- Dual scanning pencil-beam scatterometer
- Heritage: Seasat, NSCAT
- Acquires all-weather measurements of surface wind speed and direction over the global oceans



STIKSCAT:

- Six stick fan-beam scatterometer
- Heritage: Seasat, NSCAT
- Acquires all-weather measurements of surface wind speed and direction over the global oceans



SCANSCAT/STIKSCAT

SCANSCAT Parameters

Mass = 305 kg
Instrument duty cycle = 100%
Average power = Peak power = 580 W
Heater power = 50 W (replacement)
Thermal control by passive cooling
Thermal operating range = 5°C to 55°C
Average data rate = Peak data rate = 50 kbps
Pointing requirements (instrument + spacecraft):
 control = 0.02°
 knowledge = 0.02°
 stability = TBD
Instrument view angle = 49° cone about nadir (25 km resolution for basic radar cross section)
Insensitive to expected contamination environment
Physical size :
 Spinning dual antenna assembly = 3.2 m diameter x 1.6 m high
 Electronic boxes = 12" diameter x 12" high, 1 m x 1 m x 10", 1' x 1' x 1', 1' x 1' x 1'

Note: 20% contingency is included in mass and power figures

STIKSCAT Parameters

Mass = 271 kg
Instrument duty cycle = 100%
Average power = Peak power = 290 W
Heater power = 100 W (replacement)
Active thermal control by cooling loop
Thermal operating range = 5°C to 50°C
Average data rate = Peak data rate = 5.1 kbps
Pointing requirements (instrument + spacecraft):
 control = 241 arcsec per axis (1 sigma)
 knowledge = 180 arcsec per axis (1 sigma)
 stability = 396 arcsec over 1800 seconds
Instrument view angle = square ± 50° along-track by ± 50° cross-track (from nadir, 25 km resolution for basic radar cross section)
Insensitive to expected contamination environment
Physical size :
 Each of 6 antennas = 5" x 5" x 3 m (3.6 m if boom included) 15" x 19" x 9"
 48" x 36" x 10"
 33" x 19" x 10"

Note: No contingency is included in mass and power figures.

Michael Freilich, Principal Investigator

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 Assistant Professor of Oceanography at the Marine Sciences Research Center, SUNY. 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 Definition Team and is responsible for all science-related aspects of the NSCAT Project.

Co-Investigators

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

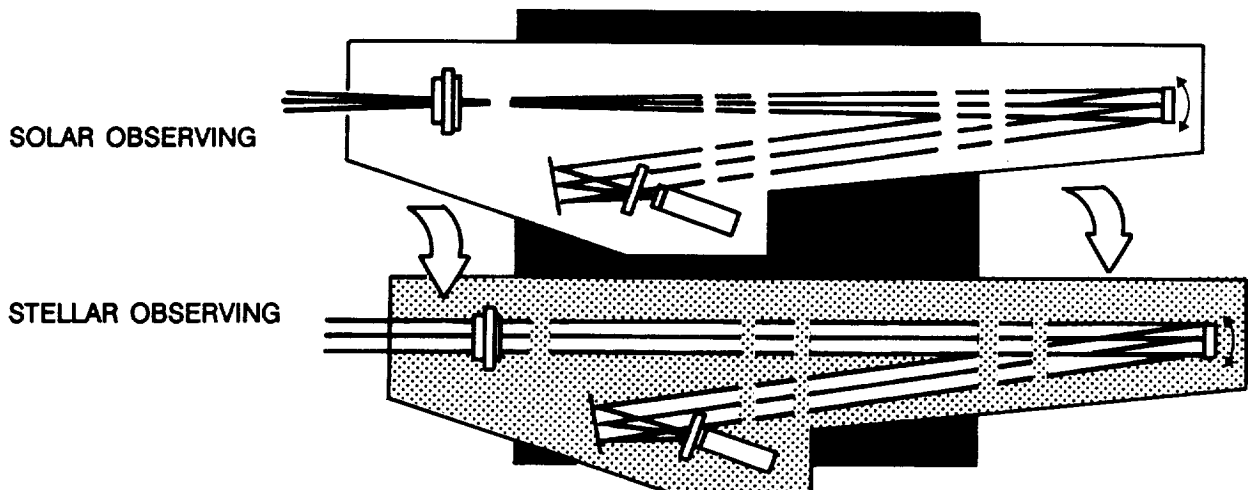
SOLSTICE

Solar Stellar Irradiance Comparison Experiment

SOLSTICE provides precise daily measurements of the full-disk solar ultraviolet irradiance between 4 to 440 nm. (Two solar spectral resolutions are required to fully determine and understand the energy input into the different layers of Earth's atmosphere.) Bright early-type stars will be used as stable, in-flight calibrations,

assuring an accuracy better than 1% throughout the entire EOS mission. The SOLSTICE instrument consists of a four-channel spectrometer together with the required gimbals drive to point SOLSTICE at the sun and stellar targets, and is similar to the UARS SOLSTICE instrument, scheduled to launch in 1991.

THE SOLSTICE INSTRUMENT



- Four-channel UV spectrometer (two-axis solar track)
- Heritage: UARS SOLSTICE
- Provides daily measurement of full-disk solar irradiance, with calibration maintained by comparison to bright, early-type stars (1% accuracy)
- 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

SOLSTICE Parameters

Mass = 147 kg (Includes 53 kg for SSPP*)
Instrument duty cycle = 100%
Average power = 67 W (Includes 40 W for SSPP*)
Peak Power = 121 W (Includes 52 W for SSPP*) (20% duty cycle)
Heater Power = 10 W
Active Thermal control =
Thermal operating range = 0° to 30°C
Average data rate = 5 kbps
Peak data Rate = 8 kbps (3% duty cycle)
Pointing requirements: (SSPP*)
 control = 6 arcmin
 knowledge = 1 arcmin
 stability = 3 arcmin
Instrument view angle = SSPP* used to point and track sun and daily selected stars (desire $\geq 180^\circ$ new angle)
Instrument IFOV = cone with 2° half-angle
Very sensitive to hydrocarbons
Physical size = 1.3 m x 0.6 m x 0.3 m, installed on TBD platform
 = 2.1 m x 2.1 m x 1.5 m, deployed and functional

*SSPP = Solar Stellar Pointing Platform

Gary Rottman, Principal Investigator

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

Co-Investigators

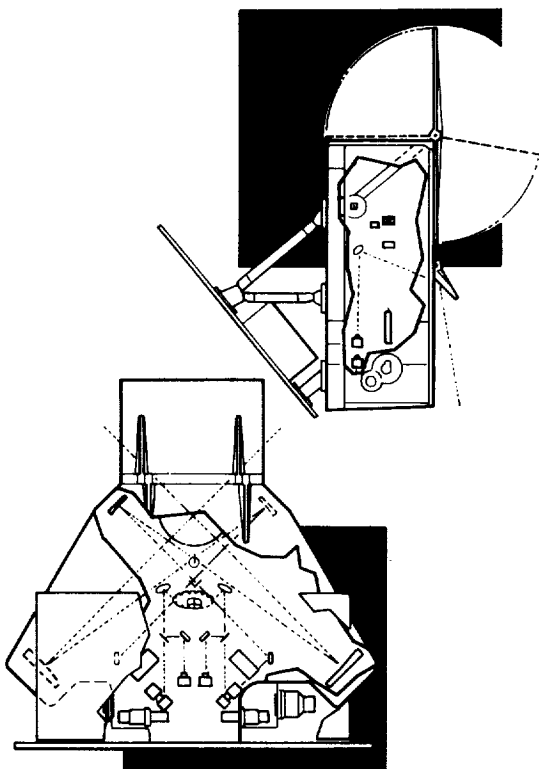
Elaine R. Hansen, University of Colorado
George M. Lawrence, University of Colorado
Jullus London, University of Colorado
Raymond G. Roble, National Center for Atmospheric Research
Paul C. Simon, Belgian Institute of Space Aeronomy
Tom N. Woods, University of Colorado

SWIRLS

Stratospheric Wind Infrared Limb Sounder

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 co-incident fields-of-view. All measurements are made continuously 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 proved inadequate for specification of transport in the stratosphere.

SWIRLS will provide the required direct measurements of wind by measuring the wind-induced Doppler shift in atmospheric emission of nitrous oxide using a powerful new gas correlation technique that employs electro-optic phase modulation (EOPM). EOPM gas correlation radiometry provides the high spectral discrimination needed to measure winds with the required spatial resolution. 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, fluxes of heat, momentum, ozone, nitrous oxide, and dynamical quantities such as potential vorticity and Eliassen-Palm fluxes.



SWIRLS MECHANICAL CONFIGURATION

- Employs limb-viewing EOPM gas correlation and filter radiometry in six spectral channels
- Observes atmospheric thermal emission in the 7.6 μm 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/s for winds, 1-2 K for temperature, and 10% for species

SWIRLS Parameters

Mass = 90 kg

Instrument duty cycle = 100%

Average power = 197 W

Peak power = 201 W

Heater Power = TBD

Thermal control by passive and active cooling

Thermal range of spacecraft interface = -30°C to 40°C

Average data rate = Peak data rate = 2130 bps

Pointing requirements (spacecraft + instrument):

control = 0.083° all axes

knowledge = 0.028° all axes

stability = 0.0042° per second, all axes

Instrument view angle = 4 simultaneous views at $\pm 45^\circ$ and $\pm 135^\circ$ wrt spacecraft x-axis, all at 65° from nadir

Instrument IFOV = 0.8° vertical by 0.44° horizontal

Detector element instantaneous FOV = 0.053° vertical by 0.44° horizontal

No special contamination sensitivity

Physical size = 150 cm x 100 cm x 40 cm

Daniel J. McCleese, Principal Investigator

Daniel McCleese was a Fulbright Scholar at Oxford University and earned his D.Phil. degree 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 Sciences 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

Fredric W. Taylor, Oxford University

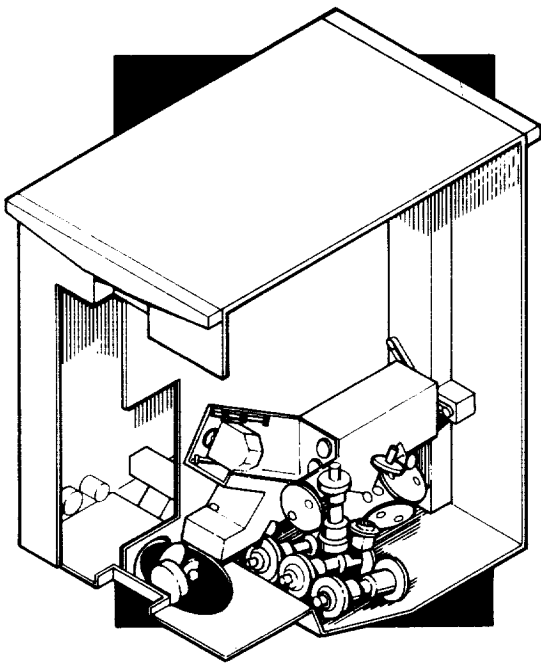
TES

Tropospheric Emission Spectrometer

TES is a high-spectral-resolution infrared imaging Fourier transform spectrometer that 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, 4) and 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 also the wide-ranging transport

and reactivity of species in the free troposphere. The approach, using both limb and nadir sensing of the thermal emission from the atmosphere and surface, generates three-dimensional profiles on a global scale of virtually all infrared-active species from the surface to the lower stratosphere. These measurements are, in turn, assimilated into global circulation models in order to assess the current, and to predict the future, state of the lower atmosphere.

TROPOSPHERIC EMISSION SPECTROMETER (TES)



- 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: $600\text{-}3450\text{ cm}^{-1}$ (2.9-17 micrometers)
- Spectral resolution: 0.025 cm^{-1}
- Maximum sampling time is 8 seconds with a signal-to-noise ratio of up to 600:1.
- Limb Mode: height resolution = 2.3 km; height coverage = 0-30 km
- Downlooking Modes--spatial resolution = 50 x 5 km (global) and 5 x .05 km (local); spatial swath = 50 x 160 km (global) and 5 x 16 km (local)

TES Parameters

Mass = 490 kg
Instrument duty cycle: 100%
Average power = 200 W (standby)
Peak Power = 700 W (600-700 W operational range)
Average data rate = 80 kbps
Peak data rate = 13.5 Mbps
Active thermal control by stirling-cycle coolers, no heater
Thermal operating range = 150 K (Instrument), 65 K (4 focal planes)
Pointing requirements (Instrument):
 control = 1 pixel
 knowledge = .1 pixel
 stability = .1 pixel
 1 pixel = 0.75 mrad x 7.5 mrad
Instrument view angle (from nadir) = elliptical cone $\pm 45^\circ$ in-track x $\pm 71^\circ$ cross-track
Instrument IFOV = (32 x 0.75 mrad) x 7.5 mrad
High contamination sensitivity to condensibles
Physical size = 1 m x 1 m x 1 m

Reinhard Beer, Principal Investigator

Dr. Beer received his B.Sc. and Ph.D. degrees 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. Dr. Beer was chairman of the NASA Infrared Experiments Working Group and now serves as Co-Investigator on the ATLAS ATMOS experiment and the proposed Cassini Probe Infrared Laser 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, AER, 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
Robert H. Norton, Jet Propulsion Laboratory
Stanley P. Sander, Jet Propulsion Laboratory
Fredric W. Taylor, Oxford University, UK
Steven C. Wofsy, Harvard University

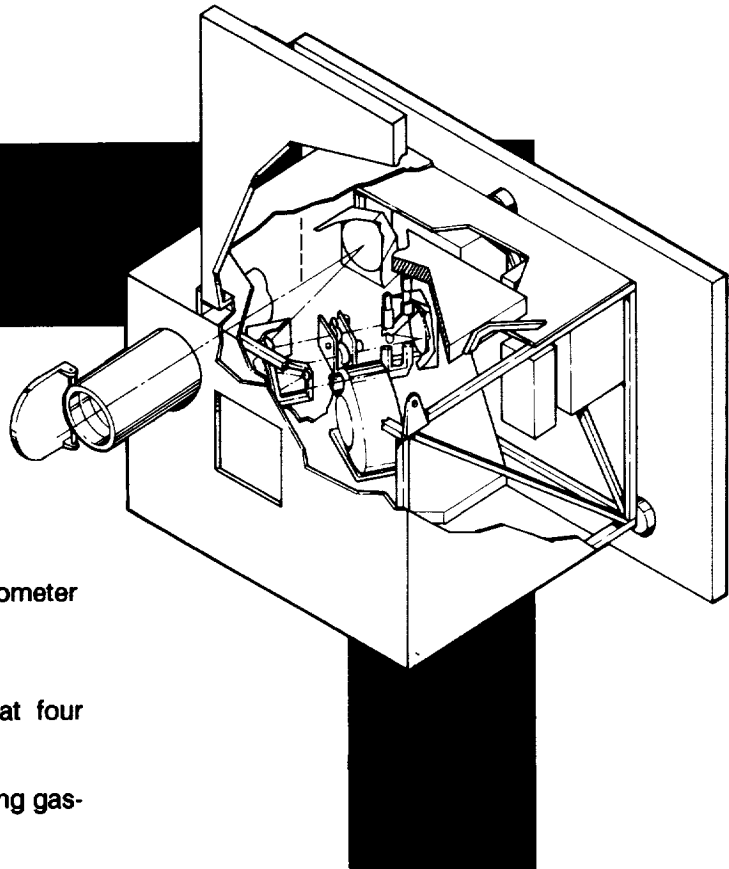
TRACER

Tropospheric Radiometer for Atmospheric Chemistry and Environmental Research

TRACER is designed to measure the global distribution of CO at multiple levels in the troposphere. This will allow the quantification of both the sources and the distribution of this most important photochemically active gas. Knowledge of the time-dependent global distribution will provide a data base for model development. These models will increase our

understanding of both global transport processes and global tropospheric chemistry. They will, for example, allow prediction of the impact of increased CO emissions on the concentration of methane, a gas that is important both to climate and to stratospheric zone.

TRACER



- Two-channel gas-filter correlation radiometer
- Heritage: MAPS/GASCOFIL
- Measures global distribution of CO at four levels in the troposphere
- Nine separate filters contained in rotating gas-cell chopper
- 2.3 micrometer radiance of CO and CH₄; 4.6 micrometer radiance of CO and N₂O

TRACER Parameters

Mass = 87 kg
Instrument duty cycle = 100%
Average power = 140 W
Peak power = 160 W (initial warm-up/standby mode only)
Heater power = TBD
Type thermal control is TBD
Thermal operating range:
 optical bench - 22.5°C
 radiators = 115 K
Average data rate = Peak data rate = 10 kbps
Pointing requirements (instrument + spacecraft):
 control = 900 arcsec
 knowledge = 900 arcsec
 stability = 240 arcsec
Instrument view angle = cone \pm 0.6° around nadir
Sensitivity to molecular and particulate contaminants; protective measures integral to design
Physical size = 48.5" x 35.5" x 28"

Henry G. Reichle, Jr., Principal Investigator

Henry G. Reichle, Jr. received an M.S. in meteorology and a Ph.D. in aeronomy from the University of Michigan. He is a Senior Research Scientist at the Langley Research Center. As Principal Investigator, he directed the development of the MAPS experiment, which made the first measurements of tropospheric carbon monoxide from an orbiting space platform.

Co-Investigators

Vickie S. Connors, Langley Research Center
Jack Fishman, Langley Research Center
Paul Fraser, CSIRO
Michael Garstang, University of Virginia
Ivar Isaksen, University of Oslo
Jennifer Logan, Harvard University
Reginald Newell, Massachusetts Institute of Technology
Ralph W. Nicholls, York University
Curtis Rinsland, Langley Research Center
Wolfgang Seiler, Fraunhofer Inst. für Atmos. Umweltforschung
H. Andrew Wallio, Langley Research Center

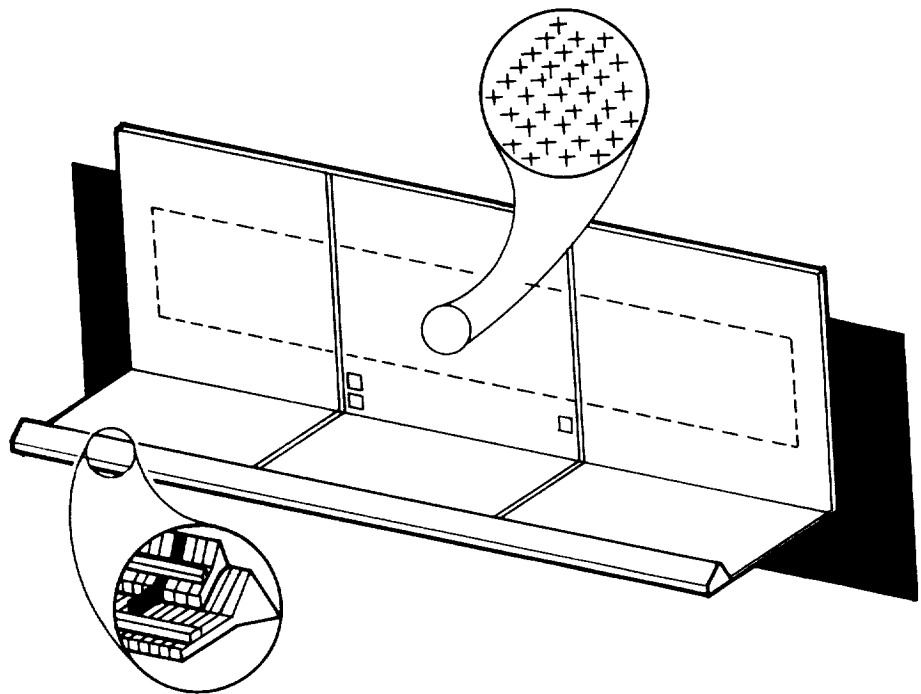
TRAMAR

Tropical Rain Mapping Radar

The Tropical Rain Mapping Radar (TRAMAR)--proposed for the manned Space Station--will provide high-resolution, accurate, rainfall data over the tropical regions to improve our understanding of the hydrological cycle, atmospheric circulation, climatological models, and mesoscale rain storm system characteristics, and provide critical data inputs to several Earth system science tasks. The TRAMAR Instrument is a dual-frequency radar that utilizes a narrow beam,

electronically scanned antenna to achieve high spatial and vertical resolutions and a relatively large swath. The dual-frequency data obtained from each rain cell are combined during ground data processing to retrieve accurate rain rate profiles over a rain rate range of 0.5 to 100 mm/hr. A nadir-looking Doppler mode is included that will provide rainfall motion and rain-rate-profile information for detailed studies of storm system characteristics.

TRAMAR



- Dual-frequency radar with narrow beam, electronically scanned antenna
- Heritage: TRMM
- Retrieves accurate rain rate profiles over 0.5 to 100 mm/hr rain rate
- Studies rainfall motion and rain rate profile

TRAMAR Parameters

Mass = 2136 kg
Instrument duty cycle = 100%
Average power = Peak power = 1226 W
Thermal control by cooling plates with fluid connection to Space Station
Average data rate = 250 kbps (160 kbps without Doppler)
Peak data rate = 9 Mbps (160 kbps without Doppler)
Pointing requirements:
 control = 0.07° (roll), 0.29° (yaw), 0.11° (pitch)
 knowledge = 40 arcsec
 stability = 10 arcsec
Instrument view angle = $\pm 150^\circ$ cross-track from nadir
Instrument IFOV (at nadir) = $< /km$ (horizontal), < 300 m (vertical)
Sensitivity to contamination is relatively insensitive to expected contaminants
Physical size = $\sim 38' \times 12.5' \times 6.2'$ (antenna)

Gerald North, *Principal Investigator*

Dr. North, who holds a Ph.D. in physics from the University of Wisconsin, has blended academic interests with Government service throughout his career. In addition to teaching assignments at the Universities of Pennsylvania and Missouri and Columbia University, Dr. North has been affiliated with numerous U.S. and international science efforts, either as guest lecturer, visiting scientist, or in other investigative capacities. He joined Goddard Space Flight Center in 1978 as Research Scientist, where he was integrally involved in the Tropical Rainfall Measuring Mission (TRMM) and received NASA achievement awards for his work on climate modeling. He joined Texas A&M University in 1986 as Distinguished Professor of Meteorology and Oceanography, and as Director of the Climate Research Program.

Co-Investigators

David Atlas, Atlas Concepts
Jeff Dozier, University of California, Santa Barbara
Fuk Li, Jet Propulsion Laboratory
Robert Houze, University of Washington
R. Eastwood Im, Jet Propulsion Laboratory
Tiruvalam Krishnamurti, Florida State University
William K. Lau, Goddard Space Flight Center
W. Timothy Liu, Jet Propulsion Laboratory
Robert Meneghini, Goddard Space Flight Center
Ken'ichi Okamoto, Communications Research Laboratory
David Short, Goddard Space Flight Center
Jagdish Shukla, University of Maryland
Joanne Simpson, Goddard Space Flight Center
Juan B. Valdes, Texas A&M University
Peter Webster, Pennsylvania State University
James A. Weinman, University of Wisconsin
Thomas Wilheit, Texas A&M University

XIE

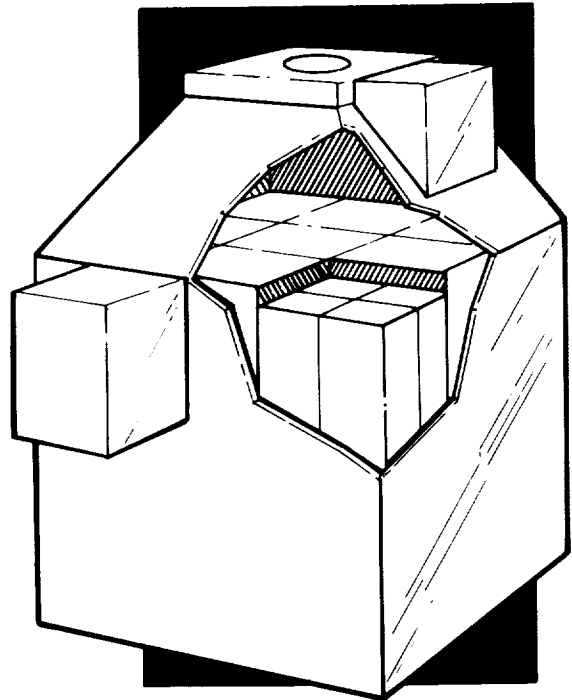
X-Ray Imaging Experiment

The objectives of the X-Ray Imaging Experiment 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 which will detect electrons from a few eV to several hundred keV and protons from a few eV to several hundred MeV. This combined package will provide information on: 1) the total x-ray

fluxes impinging on the Earth's atmosphere; 2) energy spectra of these x-rays; 3) presence of different energy spectral components, including the hard x-ray components that reach the lower atmosphere near the tropopause; 4) images of x-rays, which provide space and time information on their sources; and 5) 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.

X-RAY IMAGING EXPERIMENT (XIE)

- o X-ray pinhole Anger cameras with NaI (T1) and PM detectors for > 20 keV x-rays; proportional gas-filled counter for 3-20 keV x-rays
- o Heritage: x-ray balloons since 1976; similar instrument to be flown by Co-Investigators on Soviet spacecraft; particle detectors on Ampte/GGS Wind/Cluster
- o Detects and determines total particulate energy precipitated into Earth's atmosphere
- o Optional particle package, electrostatic analyzers (for electrons and protons from a few eV to 30 keV) and solid-state telescopes for electrons (20-450 keV) and protons (20 keV to tens of MeV)
- o Field of view $\pm 56^\circ$ (x-rays), $\pm 90^\circ$ (particles)



XIE Parameters

Mass = 85 kg

Instrument duty cycle = 100%

Average power = Peak power = 35 W

Passive Thermal control = ~10°C (x-ray scintillator)
-40°C to 20°C (particle detector)

Thermal operating range

Average data rate = 17 kbps

Peak data rate = 34 kbps (higher latitudes)

Pointing requirements (instrument star cameras):

control = ~1°

knowledge = ~1°

stability = ~1°

Instrument view angle = x-ray imager = cone \pm 56° nadir

Solid state detectors = 5 cones \pm 15° about 0°, 30°, 60°, one place, which is currently perpendicular to the spacecraft velocity vector

Electrostatic analyzers (2) = 360° in the plane of the detectors, each with an acceptance angle of \pm 15° maximum

Channel plates cannot tolerate contamination, so a cover may be provided.

Physical size:

x-ray detection system = 12" x 12" x 12"

particle detection system = 9" x 9" x 9"

platform at end of boom = 2 ft x 2 ft

George K. Parks, Principal Investigator

George K. Parks received his 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

INTERDISCIPLINARY INVESTIGATIONS

Abbott, Mark R.
Barron, Eric J.
Bates, J. Ray
Batista, Getulio T./
Jeffrey E. Richey
Brewer, Peter G.
Cihlar, Josef
Dickinson, Robert
Dozier, Jeff
Grose, William L.
Gurney, Robert J.
Hansen, James
Harris, Graham P.
Hartmann, Dennis L.
Isacks, Bryan L.
Kerr, Yann H./
Soroosh Sorooshian
Liu, W. Timothy
McNutt, Lyn
Moore, Berrien
Mouginis-Mark, Peter
Murakami, Masato
Pyle, John Adrian
Rothrock, Drew
Schimel, David M.
Schoeberl, Mark R.
Sellers, Piers
Srokosz, Meric A.
Tapley, Byron
Wielicki, Bruce

Coupled Atmosphere/Ocean Processes and Primary Production in the Southern Ocean -- Mark Abbott

Dr. Abbott's study concerns 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 nonlinear biological processes into physical models. There are two main goals: First, it will be possible 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. Second, it will be possible to understand the temporal and spatial patterns of primary production and 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 to biogeochemical and physical climate studies.

Dr. Abbott has been involved in the fields of oceanography and ecology for 11 years. He received his undergraduate degree in the conservation of natural resources from the University of California at Berkeley and the Ph.D. degree in ecology from UC, 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 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 as a member of 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
P. Ted Strub, Oregon State University

Global Water Cycle: Extension Across the Earth Sciences -- 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 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 and, in addition, serves as Editor-in-Chief of *Palaeogeography, Palaeoclimatology and Palaeoecology*, and as Editor of *Global 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
Christopher Fairall, Pennsylvania State University
Kevin Furlong, Pennsylvania State University
Thomas Gardner, Pennsylvania State University
Steven J. Goodman, Marshall Space Flight Center
C. Gregory Knight, Pennsylvania State University
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 -- J. Ray Bates

Dr. Bates plans to develop and maintain a high-resolution, four-dimensional atmosphere/ocean/land data assimilation system for the Earth Observing System. The project will involve research on all aspects of four-dimensional data assimilation (satellite retrievals, data quality control, objective analysis, initialization, and atmosphere/oceanic/land surface models), with dual objectives of extracting the maximum amount of information and understanding 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 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 kilometers.

J. Ray Bates has over 25 years 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 since 1987 has served as Senior Research Associate in the Department of Meteorology at the University of Maryland. 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/NMC
Bradley A. Ballish, NOAA/NMC
William P. Bourke, Bureau of Meteorology Research Centre
Roger Daley, Canadian Climate Centre
Dean G. Duffy, Goddard Space Flight Center
David Griersmith, Bureau of Meteorology Research Centre
H. Mark Helfand, Goddard Space Flight Center
Donald R. Johnson, University of Wisconsin
Eugenia Kalnay, NOAA/NMC
Masao Kanamitsu, NOAA/NMC
Graeme A. Kelly, Bureau of Meteorology Research Centre
John Francis LeMarshall, Bureau of Meteorology Research Centre
Lance Leslie, Bureau of Meteorology Research Centre
Graham Mills, Bureau of Meteorology Research Centre
James Pfaendtner, Goddard Space Flight Center
Chester F. Ropelewski, NOAA/NWS
Paul Schopf, Goddard Space Flight Center
Max J. Suarez, Goddard Space Flight Center
Yogesh C. Sud, Goddard Space Flight Center
Joel Susskind, Goddard Space Flight Center
H. Jean Thiebaut, NOAA/NMC
John Wallace, University of Washington
Glenn H. White, NOAA/NMC

Long-Term Monitoring of the Amazon Ecosystems Through the EOS: From Patterns to Processes-- *Getulio T. Batista*

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 priority scientifically and is the essential prerequisite for modeling change. Dr. Batista's investigation has been combined with that of Dr. Jeffrey Richey entitled, "The Regional Amazon Model: Synoptic Scale Hydrological and Biogeochemical Cycles from EOS."

The goal of the combined programs 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 hydrological 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 (especially MODIS, HIRIS, and SAR), climatological networks, and field data. With degrees in agronomy and remote sensing (Ph.D. 1981, Purdue University), 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 Brazilian Institute for Space Research (INPE). 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 Professor of Oceanography at the University of Washington in Seattle. He holds a B.A. degree in Biology from Stanford University a 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, and has been involved with the NASA SIR-B and ABLE missions.

Co-Investigators

John B. Adams, University of Washington
Marcio N. Barbosa, Instituto de Pesquisas Espaciais
Luiz A. V. Dias, Instituto de Pesquisas Espaciais
Thomas Dunne, University of Washington
Raimundo A. Filho, Instituto de Pesquisas Espaciais
Bruce R. Forsberg, Instituto Nacional de Pesquisas da Amazonia
Hermann Kux, Instituto de Pesquisas Espaciais
N. D. A. Mascarenhas, Instituto de Pesquisas Espaciais
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Compton J. Tucker, Goddard Space Flight Center
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John Wallace, University of Washington

Biogeochemical Fluxes at the Ocean/Atmosphere Interface

-- *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. The topics involved 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 JGOFS and WOCE will be involved.

Dr. Brewer received his undergraduate and Ph.D. degrees from Liverpool University and has over 20 years experience in oceanography and marine chemistry. Since 1967 he has been affiliated with the Woods Hole Oceanographic Institution, presently as Senior Scientist, and 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 and, in addition to teaching duties at W.H.O.I., has chaired or served on numerous committees concerning 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 Vice Chairman of the International Joint Global Ocean Flux Study. He is a Fellow of the American Geophysical Union.

Co-Investigators

Neil V. Blough, Woods Hole Oceanographic Institution
John L. Bullister, Woods Hole Oceanographic Institution
Dennis Clark, NESDIS/NOAA
John W. H. Dacey, Woods Hole Oceanographic Institution
Wayne Esalas, Goddard Space Flight Center
Nelson M. Frew, Woods Hole Oceanographic Institution
David M. Glover, Woods Hole Oceanographic Institution
Nancy Maynard, White House Office of Science and Technology Policy
Robert J. Olson, Woods Hole Oceanographic Institution
Edward T. Peltzer, Woods Hole Oceanographic Institution
William J. Plant, Woods Hole Oceanographic Institution
Daniel J. Repeta, Woods Hole Oceanographic Institution
Anne Thompson, Goddard Space Flight Center
Oliver C. Zafiriou, Woods Hole Oceanographic Institution

Quantifying the Vegetation of Canada: Carbon Budget and Succession Models -- 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 Vegetation Change Information System (VCIS) to routinely monitor terrestrial vegetation from space. Initial model development, algorithm development, and output generation (e.g., a vegetation map of Canada) will be done prior to EOS launch. EOS data will be optimized and applied over the Canadian landmass using the VCIS, and vegetation growth models will be developed to produce digital maps of net change in carbon storage for two different years after EOS launch. Also to be developed are one or more succession models and digital maps of future vegetation distribution

over Canada, based on observed or postulated changes in environmental conditions.

Dr. Cihlar holds degrees in soil science, physical geography, and remote sensing (Ph.D. University of Kansas, 1975), and has concentrated his research interests on renewable resources and data acquisition and analysis for land applications. He joined the Canada Centre for Remote Sensing (CCRS) in 1975 as Environmental Scientist. 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
Jean Beaubien, Canadian Forestry Service
Ronald J. Brown, Canada Centre for Remote Sensing
Hamish Kimmins, University of British Columbia
Crawford (Buzz) Holling, University of Florida

NCAR Project to Interface Modeling on Global and Regional Scales with Earth Observing System Observations -- 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 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 of the models in a global and regional context; the sea-ice component; the role of clouds; and atmospheric profiles of latent-heat release. He will use EOS for obtaining 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 has been affiliated with the National Center for Atmospheric Research since 1968; presently he is Deputy Director of the Climate and Global Dynamics Division. His principal affiliation will be with the University of Arizona after August 1990. 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 Programme, the World Climate Research Programme, and the American Meteorological Society. He has over 150 refereed publications to his credit. Finally, he is a Fellow of the American Association for the Advancement of Science, the American Geophysical Union, and the American Meteorological Society, 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
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 Jenne, National Center for Atmospheric Research
Akira Kasahara, National Center for Atmospheric Research
Jeffrey T. Kiehl, National Center for Atmospheric Research
Ying-Hwa Kuo, National Center for Atmospheric Research
William A. Reiners, University of Wyoming
Raymond G. Roble, National Center for Atmospheric Research
Anthony Slingo, National Center for Atmospheric Research
Kevin Trenberth, National Center for Atmospheric Research
Jakob van Zyl, Jet Propulsion Laboratory
Warren Washington, National Center for Atmospheric Research
JoBea Way, Jet Propulsion Laboratory
Edward Zipser, Texas A&M University
Richard W. Zurek, Jet Propulsion Laboratory

Hydrology, Hydrochemical Modeling, and Remote Sensing in Seasonally Snow-Covered Alpine Drainage Basins – 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. The overall objective and anticipated result of Dr. Dozier's investigation is a detailed understanding of the patterns and processes of the water balance and chemical and nutrient balances of seasonally snow-covered alpine watersheds. Image data from several EOS facility instruments will be used to monitor hydrologic conditions in selected watersheds and to drive hydrologic models. Hydrological and chemical sampling will be done in the field, and data will also be collected from other U.S. and foreign programs currently investigating the effects of deposition of atmospheric pollutants on high-elevation watersheds. Results will be extended spatially through combination of remote sensing with hydrologic measurements.

With undergraduate and doctoral degrees in geography (Ph.D. University of Michigan, 1973), Dr. Dozier has concentrated his research on snow hydrology and related studies in radiative transfer and remote sensing, especially on interpretation of snow properties from the Landsat TM. Since 1974 he has taught at the University of California, Santa Barbara, where he is now Professor of Geography. For the past two years he has held a joint appointment as a Senior Member of Technical Staff at JPL. He is Project Scientist for JPL's HIRIS, was selected as a HIRIS Team Member, and chairs the EOSDIS Data Advisory Panel. He served on the EOS Committee on HMMR, and he is a NASA Principal Investigator on the first ISLSCP field experiment and on the Shuttle Imaging Radar-C, as well as on the California Air Resources Board's Integrated Watershed Study. He also chairs the National Academy of Science's Committee on Glaciology and the AGU's Committee on Snow, Ice, and Permafrost, and he is an Associate Editor of Water Resources Research.

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 -- *William Grose*

Dr. Grose's team will focus on providing increased understanding of the radiative, chemical, and dynamical processes which 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. degree in physics from the College of William and Mary and the Ph.D. degree 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 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
Rolando Garcia, National Center for Atmospheric Research
Alan O'Neill, British Meteorological Office
Ellis E. Remsberg, Langley Research Center
Murry L. Salby, University of Colorado
Susan Solomon, NOAA/Aeronomy Laboratory
Richard E. Turner, Langley Research Center

Estimation of the Global Water Budget -- Robert Gurney

Dr. Gurney's research objective is to use EOS and other data to estimate global water balances for days to seasons, and to examine their variability over decades with various external forcings. Several complementary models for estimating components of the daily and long-term water budget will be implemented or calibrated using EOS data, and new combined models--that can be applied globally for the first time--will be developed. Estimates of monthly water balances for continental-scale areas will be produced. These estimates will be checked in selected areas through conventional data.

Robert Gurney has concentrated his research experience in hydrological modeling. After receiving his Ph.D. degree from the University of Bristol, he was affiliated with the Institute of Hydrology in Wallingford, England. Since 1981 he has worked with NASA's Goddard Space Flight Center, within the Hydrological Sciences Branch, and is currently Head of that Branch. Dr. Gurney has served as Principal Investigator on numerous NASA and ESA projects, and was a Deputy Study Scientist for EOS and member of the EOS Science Steering Committee. He is an Associate Editor of *Water Resources Research*, and has published widely in hydrology and remote sensing.

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
Prabhakara Cuddapah, Goddard Space Flight Center
Peter S. Eagleson, Massachusetts Institute of Technology
Marvin A. Geller, State University of New York
H. Mark Helfand, Goddard Space Flight Center
N. C. Lau, NOAA/GFDL
William K. Lau, Goddard Space Flight Center
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
Paul Schopf, Goddard Space Flight Center
Sigfried Schubert, University of Maryland
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

Interannual Variability of the Global Carbon and Energy Cycles – James E. Hansen

Dr. Hansen's team will investigate the interannual variability of key global parameters and processes in the global carbon cycle and the global thermal energy cycle. They will develop, analyze, and make available global geophysical data sets derived from pre-EOS and EOS observations in combination with models. 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 are 1) knowledge of certain Earth system processes which can be investigated via large-scale interannual variability of a number of observed parameters, 2) a mini EOS-type collection of data sets available in convenient form to other

investigators, and 3) improved definition of global measurement and data set needs for EOS.

Dr. Hansen heads the Goddard Institute for Space Studies. A student of astronomy and physics (Ph.D. 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, and, in addition to his research and administrative duties, 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 man's impact on climate (the greenhouse effect).

Co-Investigators

Inez Fung, Goddard Institute for Space Studies
Anthony Del Genio, 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--

Graham Paul Harris

This interdisciplinary investigation concerns a breadth of activities going all the way 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 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. Imperial College, London, 1969), Graham Harris has dedicated his career to the interaction of physical and biological processes and their effect on aquatic resources. He worked in the Great Lakes (Canada) from 1969 to 1983 and began his remote sensing career with the ERTS-1 simulation missions. Since 1984 he has been affiliated with Australia's CSIRO Divisions of Fisheries Research and Oceanography, first as Programme Leader and now 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 oceans remote sensing, including the Australian Polar Platform Planning Committee; and is member of editorial boards of publications on marine ecology and oceanography.

Co-Investigators

John Church, CSIRO
Richard Coleman, University of Sydney
Peter Craig, CSIRO
George Cresswell, CSIRO
Chris Fandrey, CSIRO
J. S. Godfrey, CSIRO
Eric Lindstrom, CSIRO
V. Lyne, CSIRO
Trevor McDougall, CSIRO
Gary Meyers, CSIRO
Carl Nilsson, CSIRO
M. Nunez, University of Tasmania
John Parslow, CSIRO
Graeme I. Pearman, CSIRO

Climate Processes Over the Oceans -- *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, interactions between clouds and radiative fluxes and interactions between scales of motion from the scale of boundary layer turbulence to the largest scales of planetary motion. An understanding of the climate which incorporates the interactions among all of these processes and scales is necessary to predict future changes in the climate. 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. degree 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, attaining the rank of Professor in 1988. 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). He currently is a member of the Committee on Earth Sciences of the Space Science Board of the National Research Council.

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 – *Bryan L. Isacks*

Dr. Isacks focuses on the Andes Mountains 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 basis of the work will be a comprehensive regional scale mapping of tectonics, topography, climate, hydrology, and land cover, all integrated into a GIS. The products will input into (1) modeling of the 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 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. degree 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

Teresa Jordan, Cornell University

Suzanne M. Kay, Cornell University

The Hydrologic Cycle and Climatic Processes in Arid and Semi-Arid Lands – Yann H. Kerr

Through the use of remotely sensed data we now are able to monitor the responses to changes in hydrologic fluxes, using this information to better understand the processes that cause 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 man-induced changes. Dr. Kerr's investigation has been combined with that of the University of Arizona led by Dr. Sorooshian. The LERTS/UA research teams uniquely complement each other by approaching the problem from different scale perspectives.

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.

The UA research focuses initially on understanding hydrologic processes at the watershed scale, and 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 LERTS group.

Soroosh 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 M.S. and Ph.D. degrees in systems engineering and water resources systems, respectively, from UCLA. Dr. Sorooshian is best known for his work on hydrologic modeling, specifically rainfall-runoff 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.

Trained as an undergraduate in engineering, Dr. Kerr received the Ph.D. degree 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 Jet Propulsion Laboratory. Dr. Kerr has worked mainly with NOAA/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, ISLSCP; and is a Principal Investigator for ERS-1 and MOS-1 EMDUP.

Co-Investigators

Alfredo R. Huete, University of Arizona
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Ray D. Jackson, USDA/Agricultural Research Service
Bernard Seguin, Institut National de Recherche Agronomique
Philip N. Slater, University of Arizona
James Smith, Hydrological Research Laboratory
Arthur Warrick, University of Arizona
David Woolhiser, USDA/Agricultural Research Service

The Role of Air-Sea Exchanges and Ocean Circulation in Climate Variability-- *W. Timothy Liu*

Dr. Liu's proposal is built upon ongoing studies in understanding climate changes 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 thermal and buoyancy forcing on ocean circulation. Eddy-resolving ocean general circulation models including thermodynamics with

capabilities for assimilating EOS data will be developed to provide three-dimensional views of ocean circulation and heat storage.

W. Timothy Liu has been the Principal Investigator on studies concerning air-sea interaction and satellite remote sensing since he joined Jet Propulsion Laboratory in 1979. He holds M.S. and Ph.D. degrees in atmospheric sciences from the University of Washington. Dr. Liu has served on numerous science working groups 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.

Co-Investigators

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Catherine Gautler, Scripps Institution of Oceanography
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

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

No one agency or country can collect and analyze the information necessary to develop and validate global change models. The CRYSYS Group will delineate specific data collection sites in the Canadian North and identify and access critical data bases as part of a global effort to monitor and evaluate the utility of remote sensing observations of cryospheric variables for observing the effects of global change. Objectives include: continuing to develop and implement the algorithms necessary to extract geophysical information related to the cryosphere; accessing information from other related data bases, especially in Canada, so that a complete record of information on cryospheric processes can be obtained; and using information from these sources in models to examine the effects of global change as manifested by cryospheric processes.

Lyn McNutt has been with the Canada Centre for Remote Sensing since 1984, first with the RADARSAT Project, and presently as the Ice Applications Coordinator. She received her B.A. and M.A. from the University of California, Los Angeles and a Ph.C. degree from the University of Washington. Previous research scientist positions include work at JPL on SEASAT, at NOAA/PMEL in the Marine Meteorological Group, and at the School of Oceanography, University of Washington. Ms. McNutt is also the Co- Coordinating Investigator for the Program for International Polar Ocean Research (PIPOR) and a member of the Arctic Working Group and the Remote Sensing sub-group for the Canadian IGBP.

Co-Investigators

Josef Cihlar, Canada Centre for Remote Sensing
John Falkingham, Atmospheric Environment Service
Hugh French, University of Ottawa
Barry Goodison, Canadian Climate Centre
Robert Keeley, Marine Environmental Data Service
Roy Koerner, Geological Survey of Canada

Changes in Biogeochemical Cycles -- *Berrien Moore, III*

The long-term goal of this research is to understand the primary biogeochemical cycles of the planet. Professor Moore's 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 CO₂ 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 data base management system, a graphics package, and a modern interface shell.

Professor 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. 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. Presently, Professor Moore is Director of the Institute for the Study of Earth, Oceans, and Space at the University of New Hampshire and is a Visiting Senior Scientist with the Laboratoire de Physique et Chimie Marines at the Université de Paris.

Co-Investigators

John Aber, University of New Hampshire
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 --

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 in order 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 EOS Data and Information System and will also be

maintained locally for access by the volcanology community at large.

Academically trained in environmental sciences (Ph.D. 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 Chairman of the Planetary Geosciences Division and as Associate 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 and, in addition, serves as Associate Editor of *Geology* and as Editor of the Planetology Section of *EOS*.

Co-Investigators

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Louis S. Walter, Goddard Space Flight Center
Lionel Wilson, University of Hawaii
Robert S. Wolff, Apple Computers, Inc.
Charles A. Wood, Johnson Space Center
Howard A. Zebker, Jet Propulsion Laboratory

Investigation of the Atmosphere/Ocean/Land System Related to Climatic Processes— 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: (1) developing algorithm for the objective identification of cloud types and the quantitative measurement of precipitation. Data validation of newly developed remote sensing technique will be also 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; (2) monitoring climatic changes of the sea surface temperature, sea level, and surface wind by the use of satellite observations. This will lead to production of data sets which can be incorporated in the ocean modeling study of seasonal/inter-annual variations of the Pacific and the mid-

latitudinal eddies of the ocean; and (3) examining land surface conditions such as ground wetness and snow mass. An atmospheric general circulation model will be incorporated to evaluate the impact of the 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. degree from that institution in 1974. Except for a two-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, the Typhoon Research Division. His research interests include tropical, monsoon, and satellite meteorology.

Co-Investigators

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Kenzo Shuto, Meteorological Research Institute
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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 – *John Adrian Pyle*

The objective of Dr. Pyle's research is to improve the understanding of the atmospheric dynamical, chemical, and radiation interactions and 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—both separately and together—EOS data and sophisticated, numerical dynamical/radiative/photo-

chemical models of the troposphere, stratosphere, and mesosphere now being developed in the United Kingdom.

Dr. Pyle holds the D.Phil. degree 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-Rowell, University College London
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Brian Hoskins, University of Reading
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Roy J. Moffett, University of Sheffield
Shaun Quegan, University of Sheffield
David Rees, University College London
Alan Rodger, British Antarctic Survey

Polar Ocean Surface Fluxes: The Interaction of Oceans, Ice, Atmosphere, and the Marine Biosphere— *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 which control the mass and momentum balance and extent of the sea ice cover; on understanding the feedback by which variations in ice extent affect atmospheric and oceanic circulation; and on understanding primary production in polar seas and its relation to sea ice and oceanic conditions. 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 was graduated summa cum laude from Princeton University in 1964 and earned his Ph.D. degree from the University of Cambridge in 1968. Since 1970 he has been affiliated with the University of Washington, since 1978 as 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 currently serves as Associate Editor of the *Journal of Geophysical Research*.

Co-Investigators

Roger G. Barry, University of Colorado
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Frank Carsey, Jet Propulsion Laboratory
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Nancy Maynard, White House Office of Science and Technology Policy
Michael Steele, University of Washington
Dale P. Winebrenner, University of Washington

Using Multi-Sensor Data to Model Factors Limiting Carbon Balance in Global Grasslands-- *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 semiarid ecosystems worldwide. Analytical techniques and mixing models will be developed to separate the remotely sensed canopy signal from background. Canopy parameters will then be

used as inputs to the simulation model. Multitemporal 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, and has a joint appointment in the Department of Forest and Wood 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 in the areas of trace gas exchange and global ecosystem modeling.

Co-Investigators

Brian Curtiss, University of Colorado
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William Parton, Colorado State University
Carol A. Wessman, University of Colorado

Investigate the Chemical and Dynamical Changes in the Stratosphere Up to and During the EOS Observing Period -- *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. degrees from the University of Illinois; he has 13 years research experience in atmospheric dynamics, stratospheric physics, and numerical modeling. Since 1983 Dr. Schoeberl has been affiliated with the NASA/Goddard Space Flight Center 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 NRL Publication Award and a NASA Technical Achievement Award.

Co-Investigators

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Biosphere-Atmosphere Interactions -- 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 the Earth Observing System.

Piers Sellers is an honors graduate of Edinburgh University and received his Ph.D. degree from Leeds University in 1981; he has around 10 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 presently a Faculty Research Scientist in the Department of Meteorology at the University of Maryland. He has been extensively involved with the International Satellite Land Surface Climatology Project (ISLSCP), serving as Staff Scientist for the First ISLSCP Field Experiment.

Co-Investigators

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Middle and High Latitudes Oceanic Variability Study (MAHLOVS)

-- *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 proposes to build on on-going 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 sensors to investigate the variability of the atmospheric forcing of the oceans, the consequent effect on the 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 inter-

relationships on space scales ranging from 1 to 1,000 km and time scales of days to years.

Meric A. Srokosz has 10 years 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, Institute of Oceanographic Sciences
Trevor Guymmer, Institute of Oceanographic Sciences
John Marshall, Imperial College of Science & Technology
Ian Robinson, University of Southampton

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

Byron D. Tapley

The objective of the investigation is to develop appropriate system models to use Eos data from multiple sensors in combination with other satellite and in situ data, 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 studies 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. degree in engineering mechanics at The University of Texas at Austin, and has over 30

years 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 determination of crustal motion, Earth rotation, Earth's geopotential and ocean circulation. He has served on numerous NASA advisory committees, including SESAC and the Eos Science Steering Committee. He served as Chairman, Geodesy Section, AGU. 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 member of AGU, AIAA and AAS.

Co-Investigators

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

Dr. Wielicki's investigation will provide the Earth Observing System with a consistent database of accurately known fields of radiation and of cloud properties. The 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. 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 Space Station Freedom. The combination of this 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 his Ph.D. degree 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 three-year assignment with NCAR, Dr. Wielicki joined NASA's Langley Research Center in 1980 as Research Scientist. There, he served as principal investigator on the Landsat Thematic Mapper science team; on-going investigations include work as Co-Investigator on the Earth Radiation Budget Experiment (ERBE) and a role as Project Scientist and Principal Investigator for the First ISCCP Regional Experiment (FIRE).

Co-Investigators

Bruce R. Barkstrom, Langley Research Center
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David R. Brooks, Langley Research Center
Robert D. Cess, State University of New York
Thomas P. Charlock, Langley Research Center
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Edwin F. Harrison, Langley Research Center
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V. Ramanathan, University of Chicago
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John T. Suttles, Langley Research Center
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APPENDICES

ACRONYMS

PRINCIPAL INVESTIGATOR AND TEAM LEADER POINTS OF CONTACT

TABLES

CROSS-REFERENCE INFORMATION

ACRONYMS

3D	Three-Dimensional
AAC	Active Archive Center
AATSR	Advanced Along-Track Scanning Radiometer
ABLE	Amazon Boundary Layer Experiments
ACR	Active Cavity Radiometer
ACRIM	Active Cavity Radiometer Irradiance Monitor
ADEOS	Advanced Earth Observation Satellite
AES	Atmospheric Environment Service
AGU	American Geophysical Union
AIRS	Atmospheric Infrared Sounder
AIS	Airborne Imaging Spectrometer
ALT	Altimeter
AMI	Advanced Microwave Instrument
AMRIR	Advanced Medium-Resolution Imaging Radiometer
AMS	American Meteorological Society
AMSR	Advanced Microwave Scanning Radiometer
AMSU	Advanced Microwave Sounding Unit
AMTS	Advanced Moisture and Temperature Sounder
AO	Announcement of Opportunity
APL	Applied Physics Laboratory
ATLAS	Atmospheric Laboratory
ATMOS	Atmospheric Trace Molecule Spectroscopy
ATS	Advanced Technology Satellite
ATT/PL	Attached Payload
AVHRR	Advanced Very High-Resolution Radiometer
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
BRDF	Bidirectional Reflectance Distribution Function
Cal/Val	Calibration/Validation
CCD	Charged Coupled Device
CDOS	Customer Data and Operations System
CERES	Clouds and Earth's Radiant Energy Systems
CES	Committee on Earth Sciences
CIT	California Institute of Technology
CLAES	Cryogenic Limb Array Etalon Spectrometer
CNES	Centre National d'Etudes Spatiales
CNRS	Centre National de la Recherche Scientifique
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
DADS	Data Archive and Distribution System
DLS	Dynamics Limb Sounder
DMSP	Defense Meteorological Satellite Program
DOE	Department of Energy
DOI	Department of the Interior
DWS	Doppler Wind Sensor
ELV	Expendable Launch Vehicle

EMOC	EOS Missions Operations Center
ENA	Energetic Neutral Atom
ENACEOS	Energetic Neutral Atom Camera for EOS
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
EOSSMS	EOS Space Measurement System
EPA	Environmental Protection Agency
EPOP	European Polar Orbiting Platform
ERBE	Earth Radiation Budget Experiment
ERL	Environmental Research Laboratory
EROS	Earth Resources Observation System
ESA	European Space Agency
ESSC	Earth System Sciences Committee
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EUV	Extreme Ultraviolet
FCCSET	Federal Coordinating Committee on Science, Engineering, and Technology
FRG	Federal Republic of Germany
FST	Field Support Terminal
GCRP	Global Change Research Program
GEMS	Global Environment Monitoring System
GEWEX	Global Energy and Water Cycle Experiment
GGI	GPS Geoscience Instrument
GLL	Galileo
GLRS	Geosciences Laser Ranging System
GOMR	Global Ozone Monitoring Radiometer
GOS	Geomagnetic Observing System
GPS	Global Positioning System
GRID	Global Resource Information Data Base
GSFC	Goddard Space Flight Center
HALOE	Halogen Experiment
HIMSS	High-Resolution Microwave Spectrometer Sounder
HiRDLS	High-Resolution Dynamics Limb Sounder
HIRS	High-Resolution Imaging Spectrometer
HIRS	High-Resolution Infrared Sounder
ICC	Instrument Control Center
ICE	International Cometary Explorer
ICSU	International Council of Scientific Unions
ICWG	International Coordination Working Group
IDM	Ion Drift Meter
IDPGF	Institutional Data Products Generation Facility
IEEE	Institute for Electronics and Electrical Engineering
IFOV	Instantaneous Field of View
IGBP	International Geosphere-Biosphere Program
IICF	Instrument Investigator Computing Facility
IMC	Information Management Center
INPE	Instituto de Pesquisas Espaciais
IPEI	Ionospheric Plasma and Electrodynamics Instrument
IR	Infrared
ISAMS	Improved Stratospheric and Mesospheric Sounder

ISEE	International Sun Earth Explorer
IST	Instrument Support Terminal
ISTP	International Solar Terrestrial Physics
ITIR	Intermediate Thermal Infrared Radiometer
IWG	Investigator Working Group
JMA	Japan Meteorological Association
JPL	Jet Propulsion Laboratory
JPOP	Japanese Polar Orbiting Platform
LASA	Lidar Atmospheric Sounder and Altimeter
LAWS	Laser Atmospheric Wind Sounder
LERTS	Laboratoire d'Etudes et de Reserches en Teledetection Spatiale
LIDQA	Landsat Image Data Quality and Analysis
LIMS	Limb Infrared Monitor of the Stratosphere
LIS	Lightning Imaging Sensor
MAB	Man and the Biosphere
MAHLOVS	Middle and High Latitudes Oceanic Variability Study
MERIS	Medium-Resolution Imaging Spectrometer
MFE	Magnetic Field Explorer
MIMR	Multiband Imaging Microwave Radiometer
MIPAS	Michelson Interferometric Passive Atmospheric Sounder
MISR	Multi-Angle Imaging Spectro-Radiometer
MIT	Massachusetts Institute of Technology
MITI	Ministry of International Trade and Industry
MLS	Microwave Limb Sounder
MO	Mars Observer
MOC	Missions Operations Center
MODIS-N/T	Moderate-Resolution Imaging Spectrometer - Nadir/Tilt
MOPITT	Measurements of Pollution in the Troposphere
MOS	Marine Observation Satellite
MSFC	Marshall Space Flight Center
MSU	Microwave Sounding Unit
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NASCOM	NASA Communications
NASDA	National Space Development Agency of Japan
NATO	North Atlantic Treaty Organization
NCAR	National Center for Atmospheric Research
NESDIS	National Environmental Satellite, Data, and Information Service
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
NODS	National Ocean Data System
NRC	National Research Council
NSCAT	NASA Scatterometer
NSF	National Science Foundation
NSSDC	National Space Science Data Center
NWS	National Weather Service
OCPP	Cloud Photopolarimeter
OGO	Orbiting Geophysical Observatory

OSSA	Office of Space Science and Applications
OSTP	Office of Science and Technology Policy
P/S	Planning and Scheduling
PI	Principal Investigator
PICF	Principal Investigator Computing Facility
PMR	Pressure Modulated Radiometer
POD	Precision Orbit Determination
POEMS	POsitron Electron Magnet Spectrometer
POES	Polar-Orbiting Operational Environmental Satellites
POGO	Polar-Orbiting Geophysical Observatory
POIC	Payload Operations Integration Center
POLDER	Polarization and Directionality of Reflectances
PPR	Photopolarimeter Radiometer
PSC	Platform Support Center
PV	Photovoltaic
RA	Radar Altimeter
RAAC	Remote Active Archive Center
RPMA	Retarding Potential Mass Analyzer
RSS	Root Sum Square
S&R	Search and Rescue
SAFIRE	Spectroscopy of the Atmosphere Using Far Infrared Emission
SAGE	Stratospheric Aerosol and Gas Experiment
SAMS	Stratospheric Aerosol Measurement System
SAR	Synthetic Aperture Radar
SCF	Scientific Computing Facility
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SEM	Space Environmental Monitor
SIR	Shuttle Imaging Radar
SISEX	Shuttle Imaging Spectrometer Experiment
SMC	System Management Center
SME	Solar Mesospheric Explorer
SMMR	Scanning Multichannel Microwave Radiometer
SOLSTICE	Solar Stellar Irradiance Comparison Experiment
SPOT	Systeme Probatoire d'Observation de la Terre
SSM/I	Special Sensor Microwave/Imager
SSPP	Solar Stellar Pointing Platform
SST	Sea Surface Temperature
STA	Science and Technology Agency
SUNY	State University of New York
SWIR	Short Wavelength Infrared
SWIRLS	Stratospheric Wind Infrared Limb Sounder
TBD	To Be Determined
TDRSS	Tracking and Data Relay Satellite System
TES	Tropospheric Emission Spectrometer
TGT	TDRSS Ground Terminal
TIGER	Thermal Infrared Ground Emission Radiometer
TIR	Thermal Infrared
TM	Thematic Mapper
TMCF	Team Member Computing Facility

TOGA	Tropical Ocean Global Atmosphere
TOPEX	Ocean Topography Experiment
TRACER	Tropospheric Radiometer for Atmospheric Chemistry
TRAMMAR	Tropical Rain Mapping Radar
TRIS	Tropical Region Imaging Spectrometer
TRMM	Tropical Rainfall Measuring Mission
UARS	Upper Atmosphere Research Satellite
UK	United Kingdom
UNEP	United Nations Environment Program
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
USRA	University Space Research Associates
UV	Ultraviolet
VIS	Visible
VNIR	Visible and Near Infrared
WBDCS	Wide Band Data Collection System
WCRP	World Climate Research Program
WMO	World Meteorological Organization
WOCE	World Ocean Circulation Experiment
XIE	X-Ray Imaging Experiment

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TABLES

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AMSR Expected Performance

Channel	IFOV (km x km)	Pixel (15 rpm) (km x km)	Integration Time (ms) (15 rpm)	Radiometric Accuracy	Absolute Calibration
6.8 GHz	50 x 83	24 x 26.4	17.2	0.25 K	1.0 K
10.6 GHz	32 x 53	24 x 26.4	17.2	0.5 K	1.0 K
18.7 GHz	18 x 30	12 x 26.4	8.6	1.0 K	1.5 K
23.8 GHz	14 x 24	12 x 26.4	8.6	1.0 K	1.5 K
36.5 GHz	9.3 x 15	6 x 13.2	4.3	1.0 K	1.5 K
90 GHz	3.8 x 6.3	3 x 6.6	2.1	1.0 K	2.0 K
0.4-1 μm	2.0 x 3.3	1.5 x 3.3	1.1	S/N>3 (=1%)	--
10-11 μm	2.0 x 3.3	1.5 x 3.3	1.1	0.2 K	1.0 K

EOSP Instrument Channels

Band Center (nm)	Width FWHM (nm)	Signal-to-Noise (for scene with albedo = 0.3)
410	38	3000
470	20	4500
555	20	5300
615	15	4700
675	20	5300
750	15	4300
880	20	4300
950	20	4100
1250	60	4800
1600	60	3600
2050	100	3300
2250	100	2600

HIMSS Radiometric Performance

Channel Number	Frequency (GHz) and Polarization	Integration Time (msec)	Spatial Resolution (km)	Temperature Resolution (K)	Specified Bandwidth (GHz)	Achievable Bandwidth (GHz)
1-2	90 V,H	1.51	5	0.7	1500	6000
3-4	90 V,H	1.51	5	0.7	1500	6000
5-6	37 V,H	3.02	10	0.4	1000	1000
7-8	37 V,H	3.02	10	0.4	1000	1000
9-10	21 V,H	3.02	17	0.4	500	620
11-12	18 V,H	3.02	17	0.4	500	570
13-14	10.65 V,H	3.02	31	0.3	400	400
15-17	6.63 V,H	3.02	50	0.3	170	170
18-20	6.63 V,H	3.02	50	0.3	170	170

HiRDLS Experiment Measurement Objectives

Parameters Measured	Spectral Range (cm ⁻¹ or μm)	Alt. Range (km)	Vert. Resol. (km)	Horizontal Resolution		Temporal Resol.	Lat. Cov. (deg.)	Estimated Accuracy	
				Lat.	Long.			%	Vertical Range (km)
Temperature	590-710	10-80	1.0	4°	4°	12	-90/+90	1K 2K	10-70 70-80
Ozone	940-1150	10-80	1.0	4°	4°	12	-90/+90	10% 20% 20%	15-65 10-15 65-80
Water Vapor	1390-1580	10-80	1.0	4°	4°	12	-90/+90	10% 20%	10-65 65-80
Methane	1285-1375	10-60	1.0	4°	4°	12	-90/+90	10% 20%	10-45 45-60
Nitrous Oxide	588-590 or 1240-1305	10-40 10-50	1.0	4°	4°	12	-90/+90	10% 20% 10% 20%	10-35 35-40 10-45 45-50
Nitric Acid	850-920	20-50	1.0	4°	4°	12	-90/+90	10% 20%	20-40 40-50
CFC11	825-855	10-30	1.0	4°	4°	12	-90/+90	10% 20%	10-25 25-30
CFC12	910-945	10-35	1.0	4°	4°	12	-90/+90	10% 20%	10-30
Dinitrogen Pentoxide	1235-1255	15-40	1.0	4°	4°	12	-90/+90	20%	TBD
Nitrogen Dioxide	1565-1645	15-55	1.0	4°	4°	12	-90/+90	10%	15-55
Aerosol (several components)	1586-1410	10-50	1.0	4°	4°	12	-90/+90	varies	

1. Horizontal resolution in latitude includes the width of the horizontal weighting function and ground-track motion during measurement time, and that in longitude is taken to be the profile spacing (since any smearing is much less than the spacing); vertical resolution is taken to be the smallest resolvable atmospheric feature.

2. Only quantities that can be measured directly are included; other quantities such as wind derived by the geostrophic or gradient relationship from the temperature field, or constituents that can be deduced from those measured using assumptions about the chemistry, are not included.

3. Some quantities are measured with multiple pass bands, e.g. temperature, aerosol, water vapor and ozone. Only the extreme upper and lower limits are given.

ITIR

Wavelength Region	Band No.	Band Location	Radiometric Resolution	Spatial Resolution on the Earth Surface
Visible and Near Infrared (VNIR)	1	0.52 μm ~0.60 μm	NEDT 0.5%	15 m
	2	0.63 μm ~0.69 μm	0.5%	15 m
	3	0.76 μm ~0.86 μm	0.5%	15 m
Short Wavelength Infrared (SWIR)	4	1.60 μm ~1.71 μm	0.5%	30 m
	5	2.02 μm ~2.12 μm	0.8%	30 m
	6	2.12 μm ~2.19 μm	0.8%	30 m
	7	2.19 μm ~2.26 μm	1.0%	30 m
	8	2.29 μm ~ 2.36 μm	1.0%	30 m
	9	2.36 μm ~ 2.43 μm	1.3%	30 m
Thermal Infrared (TIR)	1	08.025 μm ~ 8.375 μm	NEDT 0.3 K	90 m
	11	8.375 μm ~ 8.725 μm	0.3 K	90 m
	12	8.725 μm ~ 9.075 μm	0.3 K	90 m
	13	10.25 μm ~ 10.95 μm	0.3 K	90 m
	14	10.95 μm ~ 11.65 μm	0.3 K	90 m

Bands 1 to 3 have stereoscopic viewing capability along the track. The base-to-height ratio is more than 0.3. The swath width is 60 km. Pointing capability is provided for the cross-track direction. The expected life is 5 years.

The modulation transfer function (MTF) is higher than 0.25 at the Nyquist frequency.

The radiometric accuracy of VNIR and SWIR is higher than 4%, and that of TIR is higher than 1 K between 270 K and 340 K, and higher than 2 K at 240 K.

MODIS-N BANDS

Band	Center*	IFOV (m)	Width	Purpose (Examples)
Land And Cloud Boundaries Bands				
1	659	214	20	veg chlorophyll abs
2	865	214	50	land cover trans. cloud and vegetation land cover transf.
Land And Cloud Properties Bands				
3	470	428	20	soil, vegetation differences
4	555	428	20	green vegetation
5	1240	428	20	leaf/canopy properties
6	1640	428	20	snow/cloud differences
7	2130	428	50	land & cloud properties
Ocean Color Bands				
8	415	856	15	chlorophyll
9	443	856	10	chlorophyll
10	490	856	10	chlorophyll
11	531	856	10	chlorophyll
12	565	856	10	sediments
13	653	856	15	sediments, atmosphere
14	681	856	10	chlorophyll fluorescence
15	750	856	10	aerosol properties
16	865	856	15	aerosol/atmospheric properties
Atmosphere/Cloud Bands				
17	905	856	30	cloud/atmospheric properties
18	936	856	10	cloud/atmospheric properties
19	940	856	50	cloud/atmospheric properties
Thermal Bands				
20	3.75	856	0.18	sea surface temperature
21	3.75	856	0.05	forest fires/volcanoes
22	3.96	856	0.05	cloud/surface temperature
23	4.05	856	0.05	cloud/surface temperature
24	4.47	856	0.05	tropospheric temperature/cloud fraction
25	4.52	856	0.05	tropospheric temperature/cloud fraction
26	4.57	856	0.05	tropospheric temperature/cloud fraction
27	6.72	856	0.36	mid-tropospheric humidity
28	7.33	856	0.30	upper-tropospheric humidity
29	8.55	856	0.30	surface temperature
30	9.73	856	0.30	total ozone
31	11.03	856	0.50	cloud/surface temperature
32	12.02	856	0.50	cloud/surface temperature
33	13.34	856	0.30	cloud height & fraction
34	13.64	856	0.30	cloud height & fraction
35	13.94	856	0.30	cloud height & fraction
36	14.24	856	0.30	cloud height & fraction

*Band center and bandwidth are in nanometers for bands 1-19 and micrometers for bands 20-36.

MLS Measurement Objectives

Parameter	Spectral range (cm ⁻¹)	Vertical range ^c (km)	Vertical resol. ^d (km)	Horizontal resolution ^a		Estimated sensitivity ^b		Notes
				cross-track (deg)	in-track (deg)	value ^e	vert. range (km)	
ClO	7, 18-22	18-70	2.5	0.1	2.5	1×10 ⁻¹⁰ vmr 3×10 ⁻¹⁰ vmr	15-40 40-60	
H ³⁵ Cl	18-22	trop-90	2.5	0.1	2.5	1×10 ⁻¹⁰ vmr 1×10 ⁻⁹ vmr	15-45 45-70	
H ³⁷ Cl	18-22	trop-80	2.5	0.1	2.5	1×10 ⁻¹⁰ vmr 1×10 ⁻⁹ vmr	15-45 45-70	
HOCl	18-22	25-45	2.5	0.1	2.5	3×10 ⁻¹⁰ vmr	25-40	1
OCIO	18-22	20-25	2.5	0.1	2.5	3×10 ⁻¹⁰ vmr	20-25	1
CH ₃ Cl	18-22	trop-40	2.5	0.1	2.5	1×10 ⁻¹¹ vmr	15-35	2
⁸¹ BrO	18-22	20-40	2.5	0.1	2.5	2×10 ⁻¹¹ vmr	20-25	1
N ₂ O	18-22	trop-65	2.5	0.1	2.5	1×10 ⁻⁸ vmr 1×10 ⁻⁷ vmr	15-50 50-70	
HNO ₃	18-22	trop-45	2.5	0.1	2.5	5×10 ⁻¹⁰ vmr	15-40	
NO	18-22	30-120	2.5	0.1	2.5	1×10 ⁻⁸ vmr 1×10 ⁻⁶ vmr	30-50 50-80	
NO ₂	18-22	30-60	2.5	0.1	2.5	2×10 ⁻⁸ vmr 8×10 ⁻⁸ vmr	30-40 40-60	1 1
H ₂ O	18-22	trop-100	2.5	0.1	2.5	~1% 1×10 ⁻⁸ vmr	15-50 50-80	
H ₂ O (liquid)	7, 18-22	near trop	2.5	0.1	2.5	~5%	near trop	
HO ₂	18-22	30-80	2.5	0.1	2.5	3×10 ⁻¹⁰ vmr 2×10 ⁻⁹ vmr	30-50 50-70	
H ₂ O ₂	18-22	30-40	2.5	0.1	2.5	1×10 ⁻⁹ vmr	30-40	1
O ₃	7, 18-22	trop-110	2.5	0.1	2.5	~1% 1×10 ⁻⁷ vmr	15-50 50-75	
O ₃ (ν ₂)	18-22	trop-70	2.5	0.1	2.5	10%	15-50	
O ₃ (ν _{1,3})	18-22	20-60	2.5	0.1	2.5	50%	15-50	1
¹⁸ O ¹⁸ O	18-22	20-60	2.5	0.1	2.5	20%	15-40	
O ¹⁸ O ¹⁶ O	18-22	20-60	2.5	0.1	2.5	50%	15-40	1
¹⁷ O ¹⁶ O ¹⁶ O	18-22	20-50	2.5	0.1	2.5	50%	15-40	1
O ¹⁷ O ¹⁶ O	18-22	25-45	2.5	0.1	2.5	100%	15-40	1
O ₂	4	trop-120	5	0.2	2.5	~1% 3×10 ⁻² vmr	15-90 90-110	
O ₂ (ν = 1)	4	20-80	5	0.2	2.5	10%	30-50	
¹⁸ O ¹⁶ O	18-22	30-80	2.5	0.1	2.5	50%	30-50	1
CO	18-22	30-120	2.5	0.1	2.5	3×10 ⁻⁸ vmr 1×10 ⁻⁵ vmr	30-60 60-100	
H ₂ CO	18-22	30-50	2.5	0.1	2.5	2×10 ⁻¹⁰ vmr	30-40	1
HCN	18-22	20-65	2.5	0.1	2.5	4×10 ⁻¹¹ vmr	20-50	2
SO ₂	18-22	20-30	2.5	0.1	2.5	5×10 ⁻¹⁰ vmr	20-30	3
pressure	2, 4, 18-22	20-70	2.5	0.1	2.5	~1%	30-50	
temperature	4, 18-22	trop-120	2.5	0.1	2.5	2 K	20-100	
wind	4, 18-22	60-110	2.5	0.1	2.5	10 m/s	80-100	4
B	4	80-100	5	0.2	2.5	2×10 ⁻³ G	80-100	5

MLS Measurement Objectives: footnotes and notes

^aLatitude coverage is 82°N – 82°S on each orbit. A vertical profile is measured every 2.5° along the Eos platform orbital track great circle (the time taken for this, including calibration on each vertical scan and scan retrace, is 42 s: $\frac{1}{144}$ of the orbit period); the *longitude* spacing of measurements varies from 25° at the equator to 2.5° at ±82° latitude. 'Cross-track' resolution gives *longitude* resolution at the equator and *latitude* resolution at ±82°; *vice-versa* for 'in-track' resolution.

^bSensitivity given here is equivalent 1 σ instrument noise for the 0.64 s instrument integration time — this allows limb scans covering 0–120 km tangent heights, with individual 0.64 s measurements every 2.5 km, to be completed (with time for calibration and retrace) in 42 s — the sensitivity given in the table is for the top end of the indicated vertical range; sensitivity improves with lower altitude. Some measurements will be averaged during data processing to improve the sensitivity at the expense of resolution: for example, monthly zonal averages with 5° latitude resolution (separate day and night) have sensitivity ~30 \times better than shown in this table. The MLS vertical scan can also be programmed to further improve sensitivity in some regions at the expense of coverage in others: a 2 \times stratospheric sensitivity improvement is obtained, for example, by scanning only the stratosphere.

^cThis altitude range is where the expected signal is >2 \times the instrument noise for monthly zonal means, or for special situations such as enhanced abundances which occur in polar spring or following volcanic eruptions. The lower altitude limit is set by interferences from spectral line wings, whose effect has been estimated; 'trop' indicates tropopause.

^dThe full vertical width between half-power points of the instrument field-of-view (IFOV) is 1.2 km for all composition measurements, except for O₂ where it is 6 km. The 'resolution' of measured profiles is, however, degraded from the IFOV resolution due to radiative transfer and retrieval processing. The nominal MLS vertical scan performs measurements in 2.5 km tangent height steps over 0–120 km vertical range; step sizes as small as ~0.1 km can be programmed.

^eVmr is 'volume mixing ratio'.

Note 1. Zonal averages are expected to be required for a useful measurement of this parameter (based on currently-expected atmospheric abundances). OCIO is expected to be measured only when its abundance is greatly enhanced, such as has been observed in the Antarctic spring.

Note 2. This parameter may not be measured simultaneously with all others.

Note 3. Useful measurements of SO₂ are expected only following large volcanic injections.

Note 4. Only the one horizontal wind component in the orbital plane is measured (by spectral line Doppler shifts).

Note 5. B is magnetic field strength (measured by Zeeman-splitting of O₂ lines). S/N of ~10 is expected for measurement of variations in B during intense solar disturbances. These measurements are simultaneous and coincident with the composition measurements, and can identify observed perturbations in composition as being due to certain solar disturbances.

MOPITT Experiment Measurement Objectives

Parameters Measured	Spectral Range (cm⁻¹ or μm)	Alt. Range	Vert. Resol. (km)	Horizontal Resolution (km)	Temporal Resolution	Lat. Cov. (deg.)	<u>Estimated Accuracy</u> Vertical % (km)
CO column	2.5 μm	-	-	22 km ²	2-5 days	Global	10% N/A
CO profile	4.7 μm	0-15	3-4	22 km ²	2-5 days	Global	10% 0.1-5 km

SAFIRE Experiment Measurement Objectives

Parameters Measured ¹	Spectral Range (cm ⁻¹)	Alt. Range (km)	Vert. Resol. (km) IFOV ²	Horizontal Resolution ³		Temporal Resolution (sec) ⁴	Estimated Accuracy ⁵	
				Lat. (deg)	Long. (deg)		%	Vertical (1σ) Range (km)
O ₃	82-84.4; 926-1141	10-100	1.5-3	1-5	25	18-72	10	10-70
O ₃ ⁵⁰	82-84.4	10-50	3	2.5-5	25	36-72	20	20-40
O(³ P)	157-159	90-180	3	2.5-5	25	36-72	30	110-180
OH	82-84.4; 117.8-119.6	20-90	3	2.5-5	25	36-72	15	30-75
HO ₂	93.8-96; 111.0-112.6	20-75	3	2.5-5	25	36-72	15	30-60
H ₂ O ₂	93.8-96	20-50	3	2.5-5	25	36-72	15	30-35
H ₂ O	157-159	10-100	3	2.5-5	25	36-72	10	20-80
HDO	93.8-96	10-60	3	2.5-5	25	36-72	15	20-50
CH ₄	1335-1365	10-65	1.5	1-5	25	18-72	15	15-55
NO ₂	1560-1630	15-60	1.5	1-5	25	18-72	10	20-55
HNO ₃	850-920	10-45	1.5	1-5	25	18-72	15	15-40
N ₂ O ₅	310-390; 1230-1260	10-45	1.5-3	1-5	25	18-72	20	20-40
HCl	82-84.4	10-65	3	2.5-5	25	36-72	10	25-55
HOCl	98.5-100; 117.8-119.6	20-45	3	2.5-5	25	36-72	15	35-40
HBr	98.5-100	15-40	3	2.5-5	25	36-72	20	25-35
HF	82-84.4	40-60	3	2.5-5	25	36-72	30	40-60
Temp.	630-670; 580-760	10-110	1.5	1-5	25	18-72	<3K	16-70
Pressure	630-670; 580-760	10-110	1.5	1-5	25	18-72	3	16-70
O ₂	82-120	10-80	3	1-5	25	36-72	3	10-65

¹Does not include derived quantities such as winds, potential vorticity, and others.

²Vertical resolution is determined by the instantaneous field of view (IFOV).

³Latitude coverage is 82°N-82°N. Latitudinal resolution is determined by vertical profile skew or ground-track motion during the measurement time. Longitudinal resolution is determined by the orbital spacing. The horizontal FOV width is ≈ 0.1°.

⁴Observations are made continuously with a scan time of 72 sec in chemistry and thermospheric mode, 36 sec in polar chemistry mode, and 18 sec in dynamics mode.

⁵Accuracy is 1σ uncertainty determined from simulation set of 5 retrievals, except for HDO and O₃⁵⁰, which are for a single retrieval only.

SAGE III EXPERIMENT MEASUREMENT OBJECTIVES

Parameters Measured in Occultation	Spectral Range (μm)	Alt. Range (km)	Vert. Resol. (km)	Horizontal Resolution		Temporal Resolution (min)	Lat. Cov. (deg.)	Estimated Accuracy	
				Lat. (deg.)	Long. (deg.)			%	Vertical Range (km)
<u>SOLAR</u>									
Aerosol	0.385, 0.440, 0.525, 0.760, 0.930, 1.020, 1.550	0-35	1	<1	<2	-2	40S to 40N* 50N to 70N 60S to 90S	5	At aerosol peak
Cloud top PSC's	0.385, 0.440, 0.525, 0.760, 0.930, 1.020	0-35	1	<1	<2	-2	40S to 40N* 50N to 70N 60S to 90S	5	At aerosol peak
PMC's	0.385, 0.440, 0.525	80-90					40S to 40N* 50N to 70N 60S to 90S	5	
Ozone	0.290 and 0.600	6-80	1	<1	<2	-2	40S to 40N* 50N to 70N 60S to 90S	5	At [O ₃] peak
NO ₂	0.430-0.450	10-50	1	<1	<2	-2	40S to 40N* 50N to 70N 60S to 90S	10	At [NO ₂] peak
H ₂ O	0.920-0.960	3-50	1	<1	<2	-2	40S to 40N* 50N to 70N 60S to 90N	10	Trop. & lower strat.
O ₂ and Temp	0.740-0.780	6-70	1	<1	<2	-2	40S to 40N* 50N to 70N 60S to 90S	5 2K	Lower strat.
<u>LUNAR</u>									
NO ₂	0.430-0.450	10-65	2	<1	<2	-2	Varies slowly from -90 to +90	15	At [NO ₂] peak
H ₂ O	0.920-0.960	3-50	2	<1	<2	-2	Varies slowly from -90 to +90	15	Trop. & lower strat.
NO ₃	0.640-0.680	15-65	2	<1	<2	-2	Varies slowly from -90 to +90	15	Mid to upper strat.
OCIO	0.360-0.400	15-30	2	<1	<2	-2	Varies slowly from -90 to +90	20	At [OCIO] peak during "disturbed" conditions
O ₂ and Temp	0.740-0.780	6-65	2	<1	<2	-2	Varies slowly from -90 to +90	5 2K	Lower strat.

*coverage from Space Station Freedom

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