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MTPE EOS

Reference Handbook

NASA - Goddard Space Flight Center

Mission to Planet Earth (MTPE)

Earth Observing System (EOS)

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Preface

This 1995 edition of the Mission to Planet Earth/Earth Observing System (MTPE/EOS) Reference Handbook has been prepared to present the latest status of this evolving program.

A special feature of this edition is the set of extended descriptions of the Interdisciplinary Investigations (IDS) that uniquely make up the scientific core of EOS. The 29 Interdisciplinary Teams have been in place from the very beginning of EOS. It is their special function to perform the scientific analyses that will benefit from the vast array of remote-sensing data that is now becoming available from various sources. They are developing and applying the skills needed to take advantage of data from the highly sophisticated instruments that will be launched onboard EOS satellite platforms and onboard the complementary satellite platforms from the international community.

Functioning in an interactive mode, they are testing the capabilities of NASA's new Earth Observing System Data and Information System (EOSDIS). At this time, prior to launch of the first EOS spacecraft in 1998, they are using early versions of EOSDIS to perform their scientific studies. Their experiences in using the system then permit them to feed back suggestions for improvement to the EOSDIS developers.

The scientific investigations associated with EOS instruments play a major role in supporting overall EOS science objectives. The geophysical parameters that are supplied to the interdisciplinary investigations as EOS instrument products are themselves the products of considerable research activities by members of the many EOS instrument teams. Research by the instrument team members makes possible the conversion of instrument signals to the geophysical parameters that are then used by the interdisciplinary investigators in their work. The instrument team members not only provide the geophysical parameters (standard instrument products), but also participate in the field experiments and mathematical analyses required to provide the necessary assurances of the validity of the data. They also conduct inter-instrument investigations that are the basis for multi-sensor products that would not be available from instruments flying alone.

New in this edition is the list of standard products that is appended to each of the instrument descriptions. Also to be noted is the presentation of Landsat-7 as a new mission within EOS. A new section on Education highlights NASA's great interest in seeing that the benefits of scientific studies are extended as far as possible to the general public as well as to scientists around the world.

An electronic version of this Handbook will soon replace its 1993 predecessor on the World Wide Web. This site can be directly accessed at URL: **http://spso.gsfc.nasa.gov/eos_reference/TOC.html**.

We, as EOS Program Scientist and EOS Senior Project Scientist, hope that readers will find this document useful. We will be glad to receive any comments or questions you may have.

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Mission to Planet Earth

Mission to Planet Earth

Background

In the next century, planet Earth faces the potential hazard of rapid environmental changes, including climate warming, rising sea level, deforestation, desertification, ozone depletion, acid rain, and reduction in biodiversity. Such changes would have a profound impact on all nations, yet many important scientific questions remain unanswered. For example, while most scientists agree that global warming is likely, its magnitude and timing (especially at the regional level) are quite uncertain. Additional information on the rate, causes, and effects of global change is essential to develop the understanding needed to cope with it. The National Aeronautics and Space Administration (NASA) is working with the national and international scientific communities to establish a sound scientific basis for addressing these issues through research efforts coordinated under the U.S. Global Change Research Program (USGCRP), the International Geosphere-Biosphere Program (IGBP), and the World Climate Research Program (WCRP).

Scientific research shows that the Earth has changed over time, and continues to change. Human activity has altered the condition of the Earth by reconfiguring the landscape, by changing the composition of the global atmosphere, and by stressing the biosphere in countless ways. There are strong indications that natural change is being accelerated by human intervention. In its quest for improved quality of life, humanity has become a force for change on the planet, building upon, reshaping, and modifying nature—often in unintended ways.

The byproducts of human activities such as carbon dioxide, methane, nitrous oxide, and other gases trap heat emitted from the Earth's surface, thus potentially warming the global atmosphere. Measurements over the past several decades have documented a rapid rise in concentrations of these greenhouse gases (see Figure 1). Changes in other variables, e.g., global cloudiness, concentration of atmospheric dust particles, and ocean circulation patterns, also have an impact on Earth's climate. The existing space-based systems for global monitoring lack the spatial, temporal, and spectral coverage needed to provide observations of sufficient accuracy and precision to interpret the interactions among these variables, and their individual and combined contributions to global climate. Furthermore, current modeling of these interactive processes does not represent them with sufficient accuracy to generate reliable predictions of the magnitude and timing of global climate change.

Only through systematic, comprehensive research can scientists further knowledge of Earth's climate and its variations, thereby providing guidance to policy makers, who must balance the needs of constituents with the welfare of the planet and the species that inhabit it. The study of ozone levels by the Upper Atmosphere Research Program (UARP) illustrates how Earth science research yields a clear picture of human-induced global change. In the 1970s, scientists first proposed the chemical processes by which human-made chlorofluorocarbons (CFCs) deplete stratospheric ozone. After a long-term research program based on *in situ* and space-based observations, the international scientific community reached a consensus on global ozone depletion. The evidence and understanding gained from this research led to the Montreal Protocol for worldwide reduction in the production of CFCs in the 1990s.

Overview

Mission to Planet Earth (MTPE) is a NASA-initiated concept that uses space, ground-, and aircraft-based measurement systems to provide the scientific basis for understanding the climate system and its variations. NASA's contributions to MTPE include ongoing and near-term satellite missions, new missions under development, planned future missions, management and analysis of satellite and *in situ* data, and a continuing basic research program focused on process studies, modeling, and data analysis. The space-based components of MTPE will provide a constellation of satellites to monitor the Earth from space. Sustained observations will allow researchers to monitor Earth's climate variables over time to determine trends; however, space-based monitoring alone is not sufficient. A comprehensive data and information system, a community of scientists performing research with the data acquired, and extensive ground and airborne campaigns are all important components. More than any other factor, the commitment to make Earth science data easily available to the research community proves critical to mission success.

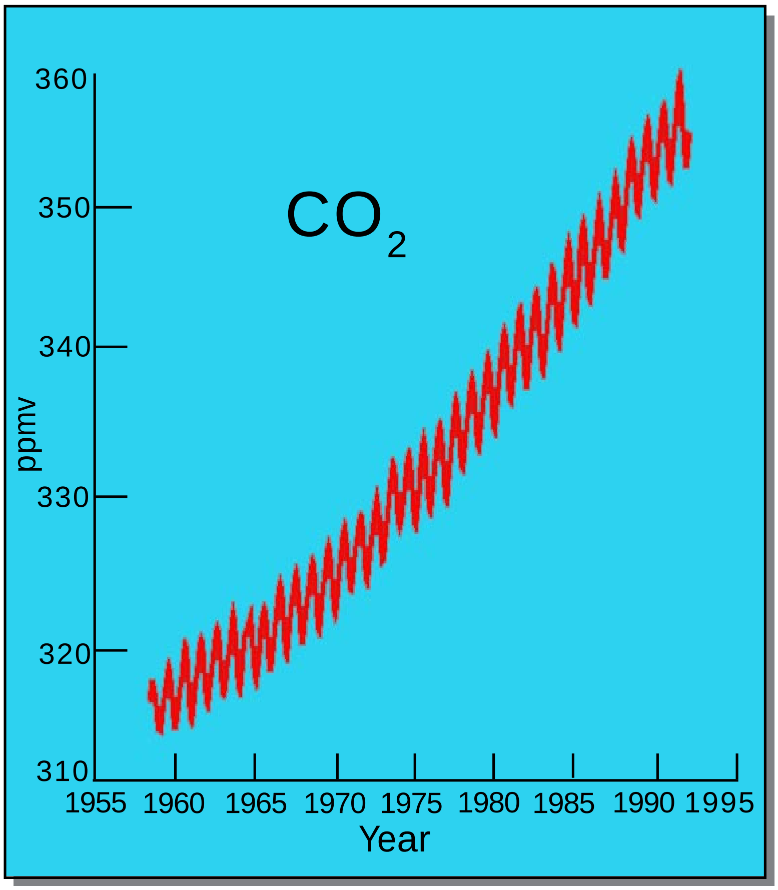


Figure 1. **Changes in Atmospheric Carbon Dioxide Concentration**
Observed by Keeling at Mauna Loa, Hawaii

Satellites stationed in a variety of orbits form the space component of MTPE. No single orbit permits the gathering of complete information on Earth processes. For example, the medium-inclination orbit of the Upper Atmosphere Research Satellite (UARS) was chosen specifically because of the Upper Atmosphere Research Program (UARP) focus on the processes influencing ozone depletion. High-inclination, polar-orbiting satellites are needed to observe phenomena that require relatively detailed observations on a routine basis, often from a constant solar illumination angle. Geostationary satellites are needed to provide continuous monitoring of high-temporal-resolution processes; an international array of these platforms now provides coverage on a near-global basis. This coverage may be improved early in the next century by geostationary satellites with advanced instrumentation planned by NASA and its international partners.

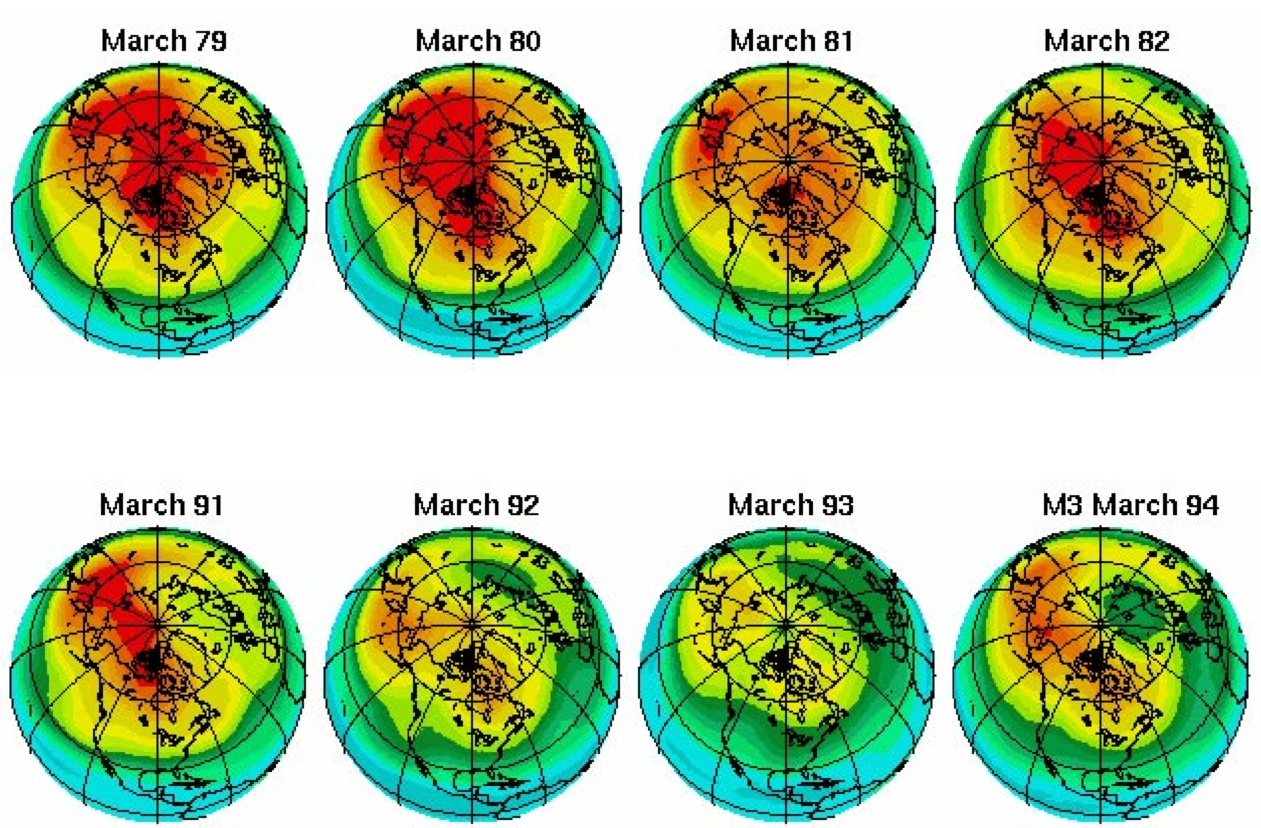
Science Objectives

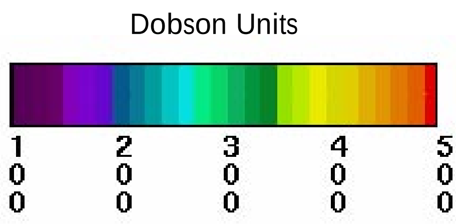
MTPE science objectives address the fundamental physical, chemical, and biological phenomena that govern and integrate the Earth system. MTPE observations will permit assessment of various Earth system processes, including the following:

- *Hydrologic processes*, which govern the interactions of land and ocean surfaces with the atmosphere through the transport of heat, moisture, and momentum.
- *Biogeochemical processes*, which contribute to the formation, dissipation, and transport of trace gases and aerosols, and their global distributions.
- *Atmospheric processes*, which control the formation, dissipation, and distribution of clouds and aerosols and their interactions with solar radiation.

METEOR-3/TOMS

Variation in polar stratospheric ozone concentrations observed by the Total Ozone Mapping Spectrometer (TOMS) on the Meteor-3 satellite, which is a cooperative scientific mission of the U.S. and Russia. (Darkest regions indicate greatest loss of ozone.)





- *Ecological processes*, which are affected by and/or will affect global change, and their response to such changes through adaptation.

- *Geophysical processes*, which have shaped or continue to modify the surface of the Earth through tectonics, volcanism, and the melting of glaciers and sea ice.

The goal of MTPE is to advance scientific understanding of the entire Earth system by developing a deeper comprehension of the components of that system and the interactions among them. To quantify changes in the Earth system, MTPE's principal element, the Earth Observing System (EOS), will provide systematic, continuous observations from low Earth orbit for a minimum of 15 years. EOS broad mission objectives in support of this goal are to:

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

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

- Support the overall USGCRP by acquiring and assembling a global database of remote-sensing measurements from space; priorities for acquiring these data will conform to the seven issues identified by the USGCRP and the Intergovernmental Panel on Climate Change (IPCC) as key to understanding global climate change, including:

  - the role of clouds, radiation, water vapor, and precipitation;
  - the productivity of the oceans, their circulation, and air-sea exchange;
  - the sources and sinks of greenhouse gases, and their atmospheric transformations;
  - changes in land use, land cover, primary productivity, and the water cycle;
  - the role of polar ice sheets and sea level;
  - the coupling of ozone chemistry with climate and the biosphere; and
  - the role of volcanoes in climate change.

Phase I Program: 1990 - 1998

Table 1 delineates NASA's contributions to Phase I of MTPE (the period of Earth observations preceding the first launch of NASA's EOS satellites in 1998. Table 2 identifies other U.S. and international Earth observation satellites that will be in place during this period.

Phase II Program: 1998-2014

The Earth Observing System—consisting of a science segment, a data system, and a space segment made up of a series of polar-orbiting and low-inclination satellites for long-term global observations of the land surface, biosphere, solid Earth, atmosphere, and oceans—is the centerpiece of MTPE. In concert with EOS, the polar-orbiting and mid-inclination platforms from Europe, Japan, and the U.S. National Oceanic and Atmospheric Administration (NOAA) form the basis for a comprehensive International Earth Observing System (IEOS). NASA, Japan, and the European Space Agency (ESA) programs will establish an international Earth-observing capability that will operate for at least 15 years. IEOS will allow scientists to obtain information at many levels of detail, covering all major Earth system processes.

Table 3 identifies the NASA, other U.S., and international contributions of Earth observing satellites during the EOS period. Additional details on these satellites are presented in the *Mission Elements* section of this Handbook. EOS will carry two classes of instruments: Facility Instruments supplied by NASA in response to general mission requirements, and Principal Investigator (PI) Instruments selected through a competitive process and aimed at the focused research interests of the selected investigators. Of course, the PI Instruments are also responsive to overall EOS objectives. The *EOS Instruments* section provides details on the

NASA Satellites/Instruments (Launch Status)	Mission Objectives
ERBS *(Operational)* Earth Radiation Budget Satellite	Earth radiation budget, aerosol, and ozone data from 57° inclination orbit
UARS *(Operational)* Upper Atmosphere Research Satellite	Stratospheric and mesospheric chemistry and dynamic processes
NASA Spacelab Series *(1992 - 1994)*	A series of Shuttle-based experiments to measure atmospheric and solar dynamics (ATLAS), atmospheric aerosols (LITE), and surface radar backscatter, polarization, and phase information (SIR-C and X-SAR [joint with Germany and Italy])
TOPEX/Poseidon *(Operational)* Ocean Topography Experiment	Ocean circulation (joint with France)
LAGEOS-2 *(Operational)* Laser Geodynamics Satellite	Satellite laser-ranging for monitoring crustal motions and Earth rotation variations (joint with Italy)
SeaWiFS *(1995)* Sea-Viewing Wide Field Sensor	Purchase of ocean color data to monitor ocean productivity
TOMS/Earth Probe *(1995)* Total Ozone Mapping Spectrometer	Ozone mapping and monitoring
NSCAT/ADEOS *(1996)* NASA Scatterometer	Ocean surface wind vectors (joint with Japan)
TOMS/ADEOS *(1996)* Total Ozone Mapping Spectrometer	Ozone mapping and monitoring (joint with Japan)
TRMM *(1997)* Tropical Rainfall Measuring Mission	Precipitation, clouds, and radiation processes over tropical regions (joint with Japan)

Table 1. **MTPE Phase I: NASA Contributions**

science to be accomplished and the high-level engineering specifications for the 24 instruments now included in the EOS Program.

The EOS Program has a number of major elements other than the EOS spacecraft and instruments. These essential elements—the EOS Data and Information System (EOSDIS), interdisciplinary research, education, and international coordination—receive coverage elsewhere in this Handbook.

The data collection segment of MTPE—EOS, Earth Probes, geostationary satellites, and aircraft- and ground-based programs—will provide the comprehensive global observations necessary to understand how the processes that govern global change interact as part of the Earth system. Through this refined knowledge, models will be developed to help predict future environmental change on local, regional, and global scales. For those who make observations of the Earth system and develop models of its operation, Earth system science means the creation of interdisciplinary models that couple elements from formerly disparate sciences, such as ecology and meteorology.

Phase III Program: Future Plans

NASA's long-range planning calls for continuation of MTPE into the next century. These plans include a new generation of satellites in geostationary orbit and additional small Earth

Probe satellites addressing specific Earth science investigations. Of course, the data system aspects of MTPE will continue throughout and beyond the lifetime of the EOS mission.

In addition to the approved Earth Probes missions identified in Table 1, i.e., TOMS, NSCAT, and TRMM, several mission categories have been identified to provide critical Earth science measurements not provided by the international constellation of satellites. NASA intends to pursue collaborations with domestic and/or international partners in the following disciplines: Gravity and magnetic fields, solid Earth topography, and ocean topography. Specific instrumentation and platforms have yet to be identified for these missions. Additional small Earth Probes will be launched as particular observations are requested by the national and international science community, or as data gaps develop. The main driver behind this program is to provide focused missions in a faster, better, and cheaper manner, alleviating lengthy procurements. These small-to-moderate-sized satellites will have highly focused objectives, and obtain measurements that are not provided by EOS or other instrument suites. NASA is currently examining alternative strategies for implementation of the second and third series of EOS missions, with a particular emphasis on small-satellite technology.

As currently envisioned, NASA's Geostationary Platform Program entails a constellation of satellites making continuous observations concurrent with the polar-orbiting EOS satellites. The platforms are required to resolve dynamic processes that operate on the scale of minutes to hours, to detect unpredictable short-term events, and to observe weak signals that can only be detected by instruments capable of "staring" for relatively long periods. Much as geostationary weather satellites track storm

Non-NASA Satellites *(Launch Status)*	**Mission Objectives**
NOAA-K through N' *(U.S.—Operational)*	Earth's surface visible and infrared radiance / reflectance, infrared atmospheric sounding, and ozone measurements; space environmental monitoring
Landsat-4 / 5 *(U.S.—Operational)* Land Remote-Sensing Satellite	High spatial resolution visible and infrared radiance / reflectance and terrestrial surfaces
DMSP *(U.S.—Operational)* Defense Meteorological Satellite Program	Visible, infrared, and passive microwave atmospheric and surface measurements
ERS-1 *(ESA—Operational)* European Remote-Sensing Satellite	C-band SAR, microwave altimeter, scatterometer, and sea surface temperature
JERS-1 *(Japan—Operational)* Japan's Earth Resources Satellite	L-band SAR backscatter and high spatial resolution surface visible and infrared radiance / reflectance
ERS-2 *(ESA—Operational)* European Remote-Sensing Satellite	Same as ERS-1, plus ozone mapping and monitoring
Radarsat *(Canada—1995)* Radar Satellite	C-band SAR measurements of Earth's surface (joint U.S. / Canadian mission)
NOAA-K through -N *(U.S.—1996 on)*	Surface visible, infrared, and microwave radiance / reflectance; infrared atmospheric sounding; and ozone measurements
ADEOS *(Japan—1996)* Advanced Earth Observing Satellite	Surface visible and near-infrared radiance / reflectance, scatterometry, and tropospheric and stratospheric chemistry (joint with U.S. and France)

Table 2. **MTPE Phase I: Non-NASA Contributions**

Satellites (Launch Status)	Mission Objectives
EOS AM Series *(1998)* Earth Observing System Morning Crossing (Descending)	Clouds, aerosols, and radiation balance, characterization of the terrestrial ecosystem; land use, soils, terrestrial energy / moisture, tropospheric chemical composition; contribution of volcanoes to climate, and ocean primary productivity (includes Canadian and Japanese instruments)
Landsat-7 *(1998)* Land Remote-Sensing Satellite	High-spatial-resolution visible and infrared radiance / reflectance to monitor land surface (joint with NOAA and USGS)
EOS Color *(1998)* EOS Ocean Color Mission	Ocean primary productivity (under review)
ENVISAT Series *(ESA—1998)* Environmental Satellite	Environmental studies in atmospheric chemistry and marine biology, and continuation of ERS mission objectives
ADEOS II *(Japan—1999)* Advanced Earth Observing Satellite II	Visible-to-thermal infrared radiance / reflectance, microwave imaging, scatterometry, ozone, aerosols, atmospheric temperature, winds, water vapor, SST, energy budget, clouds, snow and ice, ocean current, ocean color / biology (includes French and U.S. instruments).
EOS Radar ALT Series *(1999)* EOS Ocean Altimetry Mission	Ocean circulation (joint with France)
EOS PM Series *(2000)* Earth Observing System Afternoon Crossing (Ascending)	Clouds, precipitation, and radiative balance; characterization of terrestrial processes; air-sea fluxes of energy and moisture; and sea-ice extent (includes European instruments)
ATMOS Series *(Japan and NASA—Proposed for 2000)* Tropical Rainfall Measuring Mission	Precipitation and related variables and Earth radiation budget in the tropics and higher latitudes; also trace gases
METOP Series *(EUMETSAT/ESA—2000)* Meteorological Operational Satellite	Operational meteorology and climate monitoring, with the future objective of operational climatology (joint with NOAA)
ALOS *(Japan-2001)* Advanced Land Observation Satellite	Land surface, cartography, and disaster monitoring
EOS CHEM Series *(2002)* EOS Chemistry Mission	Atmospheric chemical composition; troposphere-stratosphere exchange of energy and chemicals; chemistry-climate interactions; air-sea exchange of chemicals and energy (includes an ozone-measuring Japanese instrument)
EOS Laser ALT Series *(2003)* EOS Ice-Sheet Altimetry Mission	Ice sheet mass balance and cloud top and land-surface topography

Table 3. **EOS Era Remote-Sensing Satellites**

systems today, these platforms will monitor dynamic short-term phenomena that cannot be observed from polar or low-inclination orbits. The science objectives for the geostationary platforms will complement those of the polar-orbiting and inclined-orbit missions by improving understanding of short-term processes, which will then be incorporated into global Earth system models.

EOS and small Earth Probes will provide high-spatial-resolution global information, and geostationary platforms will provide a time-continuous database over the full Earth disk. The various orbits of these space-based elements of MTPE will give Earth scientists a comprehensive, cohesive set of observations—providing a wide range of scales—on Earth system processes.

Contribution to the Global Change Research Program

MTPE is NASA's contribution to the U.S. Global Change Research Program (USGCRP), which is the focal point of U.S. activities in support of the worldwide research collaboration now under way to study global change. USGCRP coordinates the efforts of numerous participating Federal agencies under the guidance of the Committee on the Environment and Natural Resources Research (CENR), itself one of nine standing research and development coordinating subcommittees under the National Science and Technology Council, which was established in November 1993. (See section on *Interagency Coordination*.)

CENR has acknowledged the absolute necessity of the remote sensing from space of certain key Earth system variables, and reaffirmed the science strategy that had earlier been put forth by its predecessor organization, the Committee on Earth and Environmental Sciences (CEES). Thus, CENR, and thereby the National Science and Technology Council, affirm the relevance of MTPE to national policy relating to global change.

References

NASA, 1995: Mission to Planet Earth Strategic Enterprise Plan. NASA/Headquarters, Mail Code YM, 300 E Street, SW, Washington, DC 20546, in press.

Another source of information, related particularly to MTPE is:

Our Changing Planet—the FY 1995 U.S. Global Change Research Program, a report by CENR. This publication outlines all of the U.S. Federal Government activities consisting of both ground- and space-based efforts in research, data gathering, and modeling activities, as well as economic research, with near- and long-term scientific and public policy benefits. Budgets are presented by agency and by scientific element. This report is expected to be published annually.

Mission to Planet Earth WWW Home Page URL:

http://www.hq.nasa.gov/office/mtpe/

EOS Program

EOS Program

Planning for the EOS mission began in the early 1980s, and an Announcement of Opportunity (AO) for the selection of instruments and science teams was issued in 1988. 458 proposals were received in response to the AO. Early in 1990, NASA announced the selection of 30 instruments to be developed for EOS, along with their science teams; 29 Interdisciplinary Science Investigation teams were also selected at that time.

EOS was recognized in 1990 as part of the Presidential initiative, Mission to Planet Earth, receiving its "new start" from Congress in October. The EOS Program was funded under a continuing resolution, and ramped up to its full funding with the approval of the FY 91 budget in January 1991. At that time, plans called for the instruments to be divided into three groups—the EOS-A and EOS-B series spacecraft, and for flight as attached payloads on Space Station Freedom. Instrument selections were also made for the proposed Japanese and European polar-orbiting satellites, then referred to as the Japanese Polar-Orbiting Platform (JPOP) and the European Polar-Orbiting Platform (EPOP). Table 4 provides the major milestones of the EOS Program to date.

Mission Planning	*1982-87*
Announcement of Opportunity	*1988*
Peer Review Process Letter Review (Academia / Government) Panel Review (Academia / Government) Prioritization Panel (Government)	*1988-89*
Definition Phase	*1989-1990*
Announcement of Selection	*1990*
New Start	*1990*
Execution Phase	*1990 on*
Restructuring Process	*1991-92*
Restructuring Confirmation	*1992*
Rescoping Process	*1992*
National Space Policy Directive 7	*1992*
Rescoping Confirmation	*1993*
Rebaselining	*1994*

Table 4. **EOS Program History**

EOS Science Objectives

The overarching goal of the EOS Program is to determine the extent, causes, and regional consequences of global climate change. The extent, e.g., the change in average temperature and the time scale over which it will occur, is presently unknown. Causes can be either natural or human-induced. Both must be understood to determine how to alter human behavior appropriately to avoid climate changes that prove most detrimental to the environment. The regional consequences, e.g., changes in precipitation patterns, length of growing seasons, severity of storms, sea level, must be understood to determine which aspects of climate change are most harmful, and how to adapt to those changes that the human species cannot avoid.

The EOS Investigators Working Group (IWG) defined the following science and policy priorities for EOS observations, based on scientific recommendations by national and international programs such as IPCC and CEES/CENR:

1) Water and Energy Cycles

Cloud formation, dissipation, and radiative properties, which influence response of the atmosphere to greenhouse forcing.

Large-scale hydrology and moisture processes, including precipitation and evaporation.

2) Oceans

Exchange of energy, water, and chemicals between the ocean and atmosphere, and between the upper layers of the ocean and deep ocean (includes sea ice and formation of bottom water).

3) Chemistry of Troposphere and Lower Stratosphere

Links to the hydrologic cycle and ecosystems, transformations of greenhouse gases in the atmosphere, and interactions inducing climate change.

4) Land Surface Hydrology and Ecosystem Processes

Improved estimates of runoff over the land surface and into the oceans.

Sources and sinks of greenhouse gases.

Exchange of moisture and energy between the land surface and atmosphere.

Changes in land cover.

5) Glaciers and Polar Ice Sheets

Predictions of sea level and global water balance.

6) Chemistry of the Middle and Upper Stratosphere

Chemical reactions, solar-atmosphere relations, and sources and sinks of radiatively important gases.

7) Solid Earth

Volcanoes and their role in climatic change.

The IWG—which includes all selected Interdisciplinary Science Investigation Principal Investigators (PIs), Instrument Investigators, and Facility Instrument Team Leaders and Team Members—establishes EOS science objectives in coordination with the national and international Earth science community.

The IWG and the following Panels and Working Groups provide NASA with recommendations related to the design and implementation of all elements of EOS:

Science Panels

Atmosphere
Biogeochemical Cycles
Land
Modeling
Oceans
Physical Climate and Hydrology

Functional Panels

Data Quality
Communication / Education
EOSDIS
Payload
Precision Orbit Determination / Mission Design

Working Groups

SWAMP (Science Working Group for the AM Platform)
Cryosphere Working Group

The EOS Program provides resources to support the scientific research required to turn satellite measurements into science data products for inclusion in, or comparison with, model results; specifically, EOS supports scientific investigations through its Interdisciplinary Science Investigations and Instrument Teams:

- EOS Interdisciplinary Science Investigations are scientific studies selected through a competitive process to develop and refine integrated Earth system models, which will use EOS instrument observations to help in understanding the Earth as a system (see the *EOS Interdisciplinary Science Investigations* section for details on the 29 studies chosen as part of the EOS Program).

  NASA plans to issue an announcement of opportunity to invite additional interdisciplinary research proposals, to be funded in 1995/1996. It is envisioned that other such solicitations will take place once every two-to-three years to allow broader participation in the EOS Program by members of the Earth Science community.

- EOS Instrument Teams, also selected through a competitive process, help define the scientific requirements for their respective instruments, and generate the algorithms that will be used to process the data into useful data products. (See the Algorithm Theoretical Basis Documents [ATBDs] on the World Wide Web for an in-depth presentation of the algorithms. Each ATBD table of contents may be viewed, and printable copies may be downloaded by accessing location **http://spso.gsfc.nasa.gov/atbd/pg1.html**).

  NASA intends to form new Science Teams for the Landsat and EOS radar altimetry missions, and the ODUS facility instrument through an announcement of opportunity in 1995. New investigations will also be solicited in support of other EOS facility instruments such as AIRS, MODIS, and MIMR. It is envisioned that this opportunity will be renewed once every two-to-three years to allow broader participation in the EOS Program by members of the Earth Science community.

EOS investigations are intended to characterize the Earth system as an integrated whole, while also quantifying the regional processes that govern it. Research will be based initially on the existing sources of ground- and space-based observations (see *Pathfinder Data Sets* section), and will continue through and beyond the launch of the EOS satellites. Efforts to understand these Earth system elements will shed light on how the Earth functions as a coupled and integrated system, how it responds to human-induced perturbations, and how this response manifests itself as global climate change.

Refer to the *EOS Data and Information System* section of this Handbook for a discussion of the different types of products to be made available as EOSDIS evolves to a full operational capability.

The EOS Program has undergone major revisions since the last edition of this Handbook was published. The following subsection provides an overview of the successive reconfigurations of the program, which resulted from a Congressional mandate and Executive Branch requirements to substantially reduce the budget through 2000. The *Pathfinder Data Sets* section is intended to inform readers of what is being done now to further global change research. A section on *Interagency Coordination* presents the roles played by other Federal agencies, in cooperation with NASA, to make and analyze observations of Earth. The *Mission Elements* section provides details of the international instrument suites that constitute the International Earth Observing System (IEOS). This section provides as comprehensive and up-to-date coverage as possible, given the transient nature of payload configurations imposed by constrained national budgets the world over. This section and the *EOS Instruments* section describe the current Earth remote-sensing satellite scenario and the instrumentation that will yield the observations needed to further global change research.

The section on *EOS Interdisciplinary Science Investigations* gives a broad picture of the many science investigations that are in place to perform Earth System Science, taking particular advantage of the unprecedented flow of Earth observations to be provided from a variety of sources.

The Restructuring Process (1991)

In 1991, as directed by the U.S. Congressional Committee on Appropriations, the original plans for EOS were restructured for three principal reasons:

- focus the science objectives of EOS on the most important problem of global change— global climate change.
- increase the resilience and flexibility of EOS by flying the instruments on multiple smaller platforms, rather than a series of large observatories.
- reduce the cost of EOS across the board, i.e., spacecraft, instruments, data system, and science, from $17 billion to $11 billion through FY 2000.

To meet these constraints, NASA restructured the EOS Program via a thorough review by an external engineering committee and evaluation by the scientists who will use the EOS data. The review was preceded by systematic engineering studies of spacecraft configurations and launch options. The basic guiding principles for restructuring follow:

- Ensure continuity of observations for 15 years (though some instruments may be superseded or fly only once).
- Use the reports of IPCC, the EPA, and CEES to prioritize policy-relevant science questions.
- Identify a minimum complement of instruments to address each question.
- Identify those instruments whose measurement objectives can be met by existing and/or potential instruments provided by others.
- Deselect instruments where possible and as appropriate.

In July 1991, an EOS External Engineering Review (EER) Committee, headed by Dr. Edward Frieman, Director of the Scripps Institution of Oceanography, convened in La Jolla, California. NASA management and selected Interdisciplinary Science Investigation (IDS) PIs briefed the EER Committee on the Congressional constraints, their opinions regarding reconfiguration, and options that they should consider. The EER Committee endorsed the presented options in its report as a "proof-of-concept" for an EOS that contains a "favorable measure of resiliency." In August 1991, NASA discussed payload options at the Seattle EOS IWG meeting; in October, a formal review was conducted by the EOS Payload Panel in Easton, Maryland. (At that time the latter body was composed of the EOS IDS PIs, and was formally charged with examining and recommending EOS payloads to NASA based on the scientific requirements and priorities established by the Earth science community at large.) Concurrently, extensive engineering studies were conducted at the Goddard Space Flight Center (GSFC) to determine the most effective spacecraft configurations so that the instruments could be accommodated on smaller platforms. In December 1991, the NASA Administrator conducted a thorough review and approved the restructured EOS Program.

On March 9, 1992, NASA submitted a report on the restructuring of EOS to the Committees on Appropriations of the House of Representatives and Senate. Congress endorsed its contents as both comprehensive and fiscally responsible, with the final payload configurations for the restructured EOS satisfying all Congressional constraints. EOS focused on climate change; the observatories originally slated for launch aboard Titan IV expendable launch vehicles (ELVs) were to be launched on multiple smaller platforms via smaller ELVs; and the program was to have a total cost of $11 billion through FY 2000. The final payloads were very similar to those endorsed by the EER Committee and wholly consistent with its recommendations. These payloads satisfied the recommendations of the EOS Payload Panel, with the caveat that some of the instruments would fly later than recommended due to budgetary constraints.

The instruments adopted as part of the restructured EOS Program were chosen to address the key scientific issues associated with global climate change. The original EOS Program covered a broader range of global change issues, including studies of stratospheric chemistry and its controlling influence on ozone depletion, aspects of solid Earth physics, and characteristics of the mesosphere and thermosphere. The baseline EOS Program included a total of 30 selected instruments. By focusing on climate change, the required instruments were reduced to 17 that needed to fly before 2002. Six were deferred, and seven were deselected during the restructuring process.

With input from the EER Committee and detailed recommendations from the EOS Payload and Science Panels, NASA reconfigured EOS to fly the 17 instruments required for global climate change studies, as follows:

1) three intermediate spacecraft series to be launched on Intermediate Expendable Launch Vehicles (IELVs),

2) one smaller spacecraft series to be launched on Medium Expendable Launch Vehicles (MELVs), and

3) two small spacecraft series to be launched on Small Expendable Launch Vehicles (SELVs).

The names of the spacecraft series, initial launch date, launch vehicle class, and disciplinary focus follow:

- **EOS AM** *(June 1998, IELV)*—Characterization of the terrestrial and oceanic surfaces; clouds, radiation, and aerosols; and radiative balance.

- **EOS Color** *(1998, SELV)*—Ocean color and productivity.

- **EOS AERO** *(2000, SELV)*—Aerosols, water vapor, and clouds from the middle troposphere through the stratosphere.

- **EOS PM** *(2000, IELV)*—Clouds, precipitation, and radiative balance; terrestrial snow and sea ice; sea-surface temperature; terrestrial and oceanic productivity; and atmospheric temperature.

- **EOS ALT** *(2002, MELV)*—Ocean circulation, ice sheet mass balance, and land-surface topography.

- **EOS CHEM** *(2002, IELV)*—Atmospheric chemical species and their transformations, and ocean surface stress.

The launch of the first EOS AM spacecraft was rescheduled to June 1998, 6 months earlier than the originally planned launch of the first large EOS observatory, EOS-A. By reducing the size of the spacecraft and its payload, it became possible to launch earlier. The launch dates of the remaining EOS spacecraft were scheduled to occur over the ensuing 4 years, through the year 2002.

The restructured program had the EOS AM and PM satellite series both employing sun-synchronous polar orbits, but with different crossing times. The EOS AM spacecraft primarily would observe terrestrial surface features; thus, a morning crossing time (when cloud cover is at a minimum over land) proved preferable. In contrast, EOS PM included a next-generation atmospheric sounder (AIRS/AMSU/MHS)—a candidate for deployment on future NOAA operational satellites. The instruments on this platform were suitable for an afternoon crossing time. Both EOS AM and PM would observe characteristics of terrestrial and oceanic surfaces, and the atmosphere. By having measurements at two different times of day, it would be possible to study diurnal variations in these features. EOS Color, ALT, and CHEM were also slated for sun-synchronous polar orbits, and EOS AERO was to have a 57° inclination.

Certain instruments were to be flown on more than one spacecraft. The Moderate-Resolution Imaging Spectroradiometer (MODIS), which is capable of observing both the Earth's surface and atmosphere, was included on both EOS AM and PM because of its synergy with other instruments on these platforms. That is, MODIS observations obtained simultaneously through the same atmospheric column are important in interpreting data from the other instruments. By flying on two separate spacecraft, MODIS—now the central instrument of EOS—would provide important redundancy to the program. MODIS would yield cloud information to complement the radiation budget observations taken by the Clouds and the Earth's Radiant Energy System (CERES) instrument, which also was scheduled to fly on both the EOS AM and PM satellites as well as TRMM. Two MODIS instruments would provide complete global ocean color measurements by avoiding sun glint over the northern hemisphere oceans and the lack of illumination over the southern oceans, to be accomplished through their complementary ascending and descending orbits. The continuity of ocean color data beyond 2000 would be assured by including MODIS on both platforms. By flying on TRMM and both EOS AM and PM, CERES would make observations from three different orbits at different times of the day, thus capturing diurnal changes in cloud cover and properties.

The Stratospheric Aerosol and Gas Experiment III (SAGE III) instrument, which measures atmospheric aerosols, would be flown on EOS AERO and CHEM to provide measurements from two different orbits (57° inclination and polar, respectively). This strategy would also guarantee complete global coverage.

As stated earlier, the science objectives resulting from the restructuring exercise narrowed the overall study of global change down to an examination of global *climate* change. The extent, causes, and regional consequences of global climate change were to be determined by:

1) providing a continuous calibrated data set of key Earth science variables in order to monitor variability and detect trends;

2) observations that would lead to an enhanced understanding of processes in order to improve predictive models; and

3) an information system for the receipt, processing, archiving, and dissemination of data to the scientific community and policy makers.

The latter two remained virtually intact from the baseline EOS Program approach; rather, the observations to be collected and the instruments that were to take the measurements came under scrutiny. The selected EOS instruments and spacecraft ensured continuity of an important time series of climate measurements, addressed the high-priority science and policy issues identified by IPCC, and were consistent with technical, budgetary, and schedule constraints.

The Program plans that came out of the restructuring exercise were tempered by the caveat that follow-on EOS spacecraft payload configurations could change, depending on the evolution of scientific understanding and/or technological developments. For example, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument on the first EOS AM platform possibly would be replaced by the High-Resolution Imaging Spectrometer (HIRIS) on EOS AM-2. The Payload Panel stipulated that actual decisions on instruments to fly on follow-on spacecraft did not need to be made immediately; rather, their rationale was to continue technology development efforts to ensure that subsequent-generation instruments were available when needed. This proved a wise approach, given that the restructuring recommendations were approved by Congress in March 1992, and that the "Red" and "Blue" Team rescoping reviews (see "rescoping process" description that follows) were initiated by the NASA Administrator a mere two months later.

Endorsement by the National Space Council

The National Space Council (NSpC), chaired by the Vice President, issued National Space Policy Directive 7 (NSPD 7) in June 1992, covering the space-based elements of USGCRP. This document directed NASA to implement the restructured EOS Program as part of an overall space-based global change observation system. Specifically, the policy directive formalized the following:

- **Establish a comprehensive, multiagency effort to collect, analyze, and archive space-based observations on global change**—The effort is led by NASA, with participation from other Government agencies.

- **Develop the EOS Program using small- and intermediate-sized satellites**—Through the use of advanced technology and reduced design complexity, these satellites can be acquired more quickly and at less cost than previously planned, allowing the timetable for obtaining critical data on global change to be accelerated.

- **Assign global change observation functions**—This category includes the development of technology, the collection of data, and the archiving of data, to be accomplished through the combined efforts of NASA, the Department of Energy (DoE), the Department of Commerce (DoC), the Department of the Interior (DoI), and the Department of Defense (DoD).

- **Encourage international cooperation in global change observation from space**—This element directs the Department of State (DoS) to support the implementing agencies.

NSPD 7 established a focused national effort to improve multiagency collaboration in developing, collecting, analyzing, and archiving space-based observations of the Earth, with the ultimate goal of improving the world's ability to detect and document changes in global climate.

NSPD 7 directed NASA to coordinate production of an interagency program plan entitled *The Space-Based Global Change Observation System (S-GCOS) Program Plan: An Assessment of Current Status and Interagency Cooperation*, which was first released in October 1992. In addition, NSPD 7 stipulated that the Working Group preparing this document identify an integrated plan for the development of new Earth remote-sensing instruments, missions, and associated technologies that involve NASA, DoE, and DoD. To meet their joint responsibilities, the participating agencies agreed on the following guidelines:

- Establish an interagency coordinating committee to guide the development and operation of S-GCOS.
- Coordinate interagency activities related to space-based global change observations, and provide an integrated S-GCOS annual report.
- Participate with the USGCRP in the development of the Global Change Data and Information System (GCDIS), of which EOSDIS is an integral element.
- Assist in the review of USGCRP milestones related to space-based observations and data management.
- Review agency programs and budgets related to space-based observations and data management.
- Coordinate space-related activities with the appropriate oversight bodies.
- Serve as liaison between S-GCOS and appropriate bodies of the National Academy of Sciences (NAS), and with other national and international bodies with interests in space-based global change observations and data management.
- Manage the programs of their respective agencies so as to meet each agency's mission requirements, while providing planned support for S-GCOS activities.

In March of each year, the annual program plan was to be submitted to CEES through the Federal Coordinating Council for Science, Engineering, and Technology (FCCSET) to NSpC, the National Security Council (NSC), the Office of Science and Technology Policy (OSTP), and the Office of Management and Budget (OMB). The annual report would address the S-GCOS architecture, existing and planned S-GCOS satellite systems, technology development activities, sensor suites, launch systems, supporting agency contributions, and data and information systems. Specifically, the plan would identify innovative flight alternatives, e.g., small satellites, or piggybacks on commercial or military launches, and sensor options that might provide the earliest possible availability of high-priority observations or would fill critical gaps in the existing observation plan.

The S-GCOS Program Plan Working Group identified three primary Earth remote-sensing areas where joint-use requirements and/or associated research and technology development would prove suitable for collaboration between NASA, DoE, and DoD: Laser remote sensing of atmospheric winds, high-resolution multispectral imaging of the Earth's surface, and synthetic aperture radar (SAR) imaging of the Earth's surface. In December 1992, working groups were established to review coordination among agency programs and schedules, science matters, data management matters, and technology improvement needs—all of which were to be addressed in the first S-GCOS Annual Report slated for release in March 1993.

The Rescoping Process (1992)

The recommendations made by the EER Committee and the consequent restructuring of the EOS Program were based on an integrated 1992-2000 budget of $11 billion, down from the $17 billion projected in 1990. In October 1992, the FY 93 appropriations bill passed by the U.S. Congress reduced the decadal budget to $8 billion; thus, in 2 years, the EOS budget was essentially cut in half. Each cut reduced the scope and resilience of the EOS Program. Obviously, lower funding required that NASA pursue only the highest priority scientific questions in support of national goals, significantly reducing the breadth of observations that were to be collected under the baseline plan of 1990.

Rescoping studies had begun soon after the restructured EOS Program was endorsed by Congress in March 1992. As part of an internal examination of all major programs, the NASA Administrator established "Red" and "Blue" Teams in May 1992, to review content, schedule, and cost. The Blue Team consisted of NASA employees (Headquarters and GSFC) who "owned" the program and budget resources; the Red Team was composed of NASA employees (augmented by Jet Propulsion Laboratory [JPL] personnel) with project management experience outside of the program in question. The Red Team was charged with challenging the current approach and suggesting innovations to help NASA streamline its programs—that is, make them faster, better, and cheaper.

The Administrator had also set a 30-percent reduction in budget as a target, i.e., from $11 to $8 billion, which was to act as a stimulus for the teams to reassess EOS content and configurations. Red and Blue Team recommendations focused on the budget for the later years, not the FY 93 request which had already been pared back consistent with the above-mentioned Congressional directive. NASA Headquarters carefully considered the input of both the Red and Blue Teams and the EOS Payload Panel to arrive at the rescoped payloads. Most changes were confined to the EOS ALT and CHEM series payloads.

Despite rescoping, EOS retained its emphasis on collecting observations over a 15-year period, but many important measurements were cancelled or deferred due to the fact that it was now a "cost-driven" program. Several instrument changes were anticipated for the later launches in the EOS AM and PM series. Some instruments now had to be provided by international partners, as was the spacecraft for the EOS AERO series.

Rescoping to an $8 billion threshold required difficult tradeoffs to minimize the adverse impact on EOS science objectives. One key choice involved reducing the amount of contingency funds held to handle unexpected problems in instrument development due to engineering and design challenges, and/or to accommodate changes in science requirements that drive specifications for the instruments and data system. This contingency had to be balanced against savings that would result from complete elimination of instruments and their associated scientific information. The Red and Blue Teams and the EOS Payload Panel recommended that NASA reduce program contingency funds in favor of a loss in future EOS design flexibility.

The Payload Panel, which represents the EOS investigators, believed that a properly structured $8 billion funding profile through the rest of this decade would be enough to design and put in place the initial components of EOS. The increased risk associated with a reduction in contingency was seen to be implicitly mitigated, because EOS is a long-term measurement program with instruments that would be flown on 5-year intervals. As such, instrument development problems or changes in science specifications could be handled in the next versions of the instruments. Obviously, some level of resilience and flexibility had to be maintained to guarantee that a fully functional EOS would be carried out regardless of ever-changing budgets, and to allow for the necessary technology developments that benefit U.S. competitiveness.

The funding profile developed under the restructured program had already reduced EOS to a near-minimum set of instruments to pursue the focused objective of global climate change. The measurement capabilities of the remaining instruments were optimized to the maximum level possible, and further reductions appeared to be unfeasible. At $8 billion, EOS had to depend increasingly on the international partners. Failure to accomplish planned international cooperation on the Advanced Earth Observing System (ADEOS), ENVISAT and METOP, the Tropical Rainfall Measuring Mission (TRMM), and their follow-on missions would leave gaping holes in IEOS. Further budget cuts could require wholesale elimination or rephasing of instruments, thus information critical to understanding global climate change would be delayed or lost.

The rescoped EOS Program retained the focus on global climate change instituted in the restructuring exercise. The EOS Program still emphasized data collection over a 15-year period; however, many important measurements were cancelled or deferred due to the high-risk technologies involved and associated cost. A brief synopsis of key rescoping developments follows:

- All commitments to fly international instruments and the June 1998 launch date for EOS AM were maintained.To the extent possible, the science requirements identified by the EOS restructuring were preserved.

- The reduction in the EOS budget increased reliance on interagency and international cooperation.

- Common spacecraft would be developed for EOS PM, CHEM, and AM-2/AM-3 (EOS AERO and ALT remained unique).

- The HIRIS instrument was eliminated, although funding for the science team was maintained through 1994 to help address key scientific questions and clearly define observational requirements.

EOS remained a long-term program, providing continuous observations of the causes of global climate change; therefore, each EOS spacecraft was to be repeated twice on 5-year centers to provide at least 15-year coverage. The only exceptions involved EOS AERO (4 follow-on launches on 3-year centers) and the one-time EOS Color mission because of the lifetime limitations associated with small ELVs. The development of EOSDIS, its support of precursor data sets and provision of a reduced set of essential data products at the launch of each EOS element, was maintained.

The principal reductions in cost resulted from the initiation of a common bus development, a decreased number of at-launch data products, increased international and interagency cooperation, increased risk, and rescoped payloads. The rescoped payloads primarily affected those platforms planned beyond 2000—namely EOS ALT and CHEM. The EOS AM-1, PM-1, AERO, and Color science objectives were preserved by maintaining their instrument complements consistent with the recommendations of the EOS Payload Panel and the restructured program.

The rescoped program placed a greater degree of risk on meeting the science objectives beyond 2000, because increased reliance on other agency and international collaborations was assumed where firm commitments were still being negotiated. In particular, the deletion of HIRIS was predicated on the joint DoD/NASA partnership in Landsat.

Developing a common spacecraft bus preserved the science objectives by increasing payload flexibility, by simplifying instrument design through a known interface, and by allowing for a launch opportunity every 18 to 30 months. This approach could only be realized if minimal redesign were required for each spacecraft and instrument grouping. The chief concern of the Red and Blue Teams and the EOS Payload Panel was to determine optimum characteristics that best supported the instrument groupings. This resulted in EOS AM-1 having a unique design, with PM-1 having the first common bus to be used on all subsequent AM, PM, and CHEM spacecraft. IELVs remained the launch vehicles of choice, because this class best accommodates the payload needs developed during the restructuring and rescoping deliberations. The EOS ALT, AERO, and EOS Color series could be accommodated on smaller ELVs.

Continuing the then-current EOS AM-1 development effort provided the greatest assurance of meeting the June 1998 launch readiness date. The EOS Program no longer required EOS AM-2 to have the same performance characteristics as AM-1. This development effort should not be considered for naught, because the AM-1 spacecraft could serve as the basis for future Landsat-class missions. This spacecraft would be able to handle multiple high-resolution instruments, which require more power, pointing, and data-handling capabilities than other EOS missions.

The payloads after 2000 were shifted primarily to take advantage of ongoing discussions between NASA and the international community. This could allow scatterometer measurements to be advanced by approximately two years, if sufficient resources were made available to accommodate the NASA Scatterometer follow-on (SeaWinds) on Japan's ADEOS II. This would provide greater assurance of the continuity of ocean wind stress and topography measurements needed to study ocean circulation and air-sea exchange of energy and chemicals. The NSCAT accommodation on the original EOS CHEM-1 payload was considered a flight-of-opportunity in order to continue the observations begun with ADEOS I, which is scheduled for launch in 1996. Such a scenario would have required that NSCAT operate for at least 6 years prior to the launch of the EOS CHEM-1 mission. The rescoped scenario assumed flight of SeaWinds in 1999, significantly reducing risk of a gap in scatterometry data.

Two French instruments onboard the TOPEX/Poseidon mission, i.e., Solid-State Altimeter (SSALT) and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS), were to provide needed altimetric observations by replacing the U.S. Altimeter (ALT) and GPS Geoscience Instrument (GGI), respectively. However, the science return would be reduced. SSALT currently does not operate in two frequencies (required for the correction of ionospheric effects), and the substitution of DORIS provides precise tracking but eliminates the sparse, but accurate atmospheric temperature profiles that GGI would generate. Both the Red and Blue Teams and the Payload Panel took these factors into consideration when weighing science return against the costs involved.

The continuation of the Landsat Program allowed the placement of the Tropospheric Emission Spectrometer (TES)—instead of HIRIS—on EOS AM-2, together with MODIS and possibly the Measurements of Pollution in the Troposphere (MOPITT) instrument. This reconfiguration also allowed the inclusion of several flight-of-opportunity instruments, i.e., Active Cavity Radiometer Irradiance Monitor (ACRIM), Solar Stellar Irradiance Comparison Experiment (SOLSTICE), and Microwave Limb Sounder (MLS), on the EOS CHEM series. These instruments generate measurements of atmospheric chemical composition, radiation, and dynamics complementary to observations currently being collected by the MLS and SOLSTICE instruments aboard UARS.

As in the restructured EOS scenario, SAGE III measurements were to be provided by both EOS AERO and CHEM satellites, which fly in 57° inclined and polar orbits, respectively. By placing this instrument in different orbits, full global coverage could be guaranteed.

Through the rescoping exercise, the EOS Program decreased instrument contingency funds to be more representative of a multiple-copy procurement, and phased instrument developments to control initial costs and bring the overall budget within the Congressionally mandated ceiling. As a result, the total number of instruments to fly on the EOS platforms (including international contributions) was reduced to 22, of which 15 would fly before 2003. ASTER was slated for only one flight, and negotiations were underway to accommodate MOPITT on the second EOS AM platform; a slot for an unspecified Japanese instrument for flight on the EOS CHEM series was held as reciprocation for the flight of SeaWinds on the ADEOS series. Of course, instrument complements could change with the evolution of scientific understanding and/or technological enhancements.

The Rebaselining Process **(1994)**

The Clinton Administration's budget request to Congress for FY 95 put the NASA budget for the Office of Mission to Planet Earth at $455.1 M for EOS and $284.9 M for EOSDIS, for a total obligational authority of $740 M. This budget request, taken together with the projected runout requirement through 2000, represented approximately a 9% reduction in the budget for the EOS Program compared to the rescoped budget approved only one year before. As a consequence, the Goddard Space Flight Center received guidelines from the Associate Administrator of Mission to Planet Earth that included directions to maintain the launch-readiness date of the AM-1 spacecraft at June 1998, to make available the elements of EOSDIS necessary to support AM-1 in June 1998 and TRMM in August 1997, and to prepare a Request for Proposals, for release in 1994, for a common spacecraft to serve as the standard platform for at least the PM-1 and CHEM-1 missions.

Due to the potentially far-reaching consequences of this budget reduction, and the further need to obtain important observations and analyses to support the U.S. Global Change Program, the Director of the Goddard Space Flight Center established 3 teams to independently examine the requirements and implementation approaches within the EOS

Program. These teams included a core Science Team (chaired by the EOS Senior Project Scientist), a Project Team (chaired by the AM Project Manager), and a Review Team (chaired by the Associate Director of Flight Projects). These teams made recommendations for implementation approaches, which were then presented at a special meeting of the EOS Payload Panel on July 19-21, 1994, in Landover, MD.

This meeting was unique in that it was the first time that a Payload Panel meeting was open to a wide participation consisting of EOS investigators, EOSDIS Data Center representatives, and contractors, and because budget planning numbers were made available to the investigators in order to help prioritize EOS mission elements. Following initial exposure to the 26 items that the 3 independent teams had identified for potential elimination or modification, there was open discussion, facilitated by the cognizant Project and Program Scientists. This enabled all interested parties to discuss the science impacts and priorities of various scenarios.

Following a 2-day plenary session, Berrien Moore, Chairman of the Payload Panel, formed 4 independent interdisciplinary and instrument teams of EOS investigators to consider the recommendations of the Goddard teams and to look at ways to fit the high-priority mission elements into the funding profile as well as the total budget that was available. A unified Payload Panel report resulted and was submitted to the Associate Administrator of the Office of Mission to Planet Earth. The Associate Administrator, under the direction of the NASA Administrator, convened a group of independent distinguished Earth scientists to further examine the scope, balance, and risks associated with the rebaselined program. This independent group briefed the NASA Administrator on its findings. (The full text of the EOS Payload Panel report can be found in the July/August 1994 issue of *The Earth Observer*, available on the World Wide Web.)

The report of the Payload Panel was entitled *Responding to the demand to reduce the Earth Observing System budget from $8 to $7.25 billion: 1990-2000*. (Portions of the introduction to the report are quoted or paraphrased here to give the sense of the Panel's findings.)

The Panel stated that "... NASA and the Earth science community have worked together to define a minimum EOS Program that can be accomplished within this new funding constraint, while retaining the basic scientific integrity of the mission and its ability, over time, to meet the needs for environmental information of policy makers concerned with global and regional climate change.

"While some of the multi-year reductions may be accomplished without serious effect on the program, it must be stated that the achievement of several essential elements, e.g., continuity of observations for 15 years, of the program are now at significantly greater risk."

Recommendations of the EOS Payload Panel follow (direct quote with minor editorial changes):

- Do not slip AM-1 or PM-1. Assume six-year launch centers. Strive not to slip CHEM-1.

- Accept cost-saving changes to EOSDIS identified by Project/Program evaluation teams; however, do not recommend the closing of any of the DAACs.

- Cancel the combined EOS Radar and Laser Altimeter Mission and rephase it as two separate missions.

  a) Fly EOS Radar ALT as a joint mission with CNES or as a GEOSAT Follow-On-II in 1999. Maintaining the TOPEX/Poseidon data record is essential for ocean circulation determination. There will be important synergism with the altimeter on ENVISAT.

- Slip EOS Laser ALT by 12 months. Determination of ice volume is an important long-term challenge to understanding climate change; however, slipping initiation of this measurement is less damaging than other cuts to the program. The Panel remains supportive of this valuable measurement; the delay is, however, damaging to the overall program.

- Move TES to CHEM-1; this enhances the scientific value of CHEM-1 and allows AM-2 to accommodate the land remote sensing instrument planned for Landsat-8 and thereby save the country and NASA the cost of a launch and spacecraft. The cost of an advanced Landsat instrument must be funded by NASA from sources other than EOS.

- Remove ACRIM, SAGE III, and SOLSTICE from CHEM-1. This increases the robustness of the mission and allows earlier flight for certain instruments. It also allows CHEM-1 to accommodate TES and remain an MELV-class mission.

  a) Even in the light of the budget difficulties expressed in the rebaselining, the EOS Payload Panel again recommends launching SAGE III in a mid-inclination orbit by 1999-2000 and flying SAGE III in a high-inclination orbit by 2000. Measurements of the profiles of important aerosols, ozone, and upper tropospheric water vapor are essential components of a climate change program. SAGE III is particularly appropriate since there is an important long-term record from SAGE II.

  b) Fly ACRIM on a small satellite by 1998-99. Obtaining a longer record of solar forcing is an essential component of a climate change program. Develop the SOLSTICE instrument for a Flight of Opportunity in 2002-03. This instrument makes key measurements in the UV, which are important for atmospheric chemistry.

- Use AM-2 to fly an ETM+ type instrument instead of a Landsat-8 mission. This high-spatial-resolution measurement stream is important to global change and valuable to the nation in many areas. This strategy, as noted, saves the cost of a Landsat-8 launch and a spacecraft.

- Cancel EOS Color but seek to fly an ocean color instrument on Landsat-7. Losing ocean color in tropical regions is too risky for a program that must address the global carbon cycle. Add the OH capability to MLS.

- Merge the ASTER and Landsat Science Teams.

- Consolidate and phase the implementation of EOSDIS DAACs.

- Phase some of the processing and archiving of EOS Standard Products.

- Reduce the ASTER Standard Product Demand Assumption.

- Slip the CHEM-1 Mission by nine months only if there is no other way to meet the funding profile and the previous recommendations."

The Current Status of the Program

The decisions that were made in consequence of the recommendations of the Payload Panel resulted in the mission schedules that are illustrated in Figures 2 and 3 and Table 5. The resulting data communication requirements are shown in Table 6. Program flight elements to 2006 are illustrated in Tables 11a through 11c in the *International Cooperation* section. These illustrations show that the major missions (AM, PM, and CHEM) are now on six-year repeat-flight intervals; the recommended split of altimetry missions between radar and laser has been adopted; TES is to be accommodated on CHEM-1; a Landsat Advanced Technology Instrument (LATI) is to be accommodated on AM-2; and a flight of SAGE III on the International Space Station Alpha has been incorporated.

The rebaselining process introduced another category of risk to the EOS Program. The intended lifetime design of all EOS instruments is 5 years while the replacement cycle is 6 years. This means, barring any launch failures, EOS instruments must operate at least one year longer to provide continuity of observations throughout the 15-year period. (The calibration strategy requires an additional 6 months of overlap between instruments on different satellites to allow their intercalibration.)

On August 17-18, 1994, the House-Senate Appropriations Conference Committee marked up the VA-HUD-Independent Agency bill for FY 95. The Conference Committee voted to increase the EOS budget by $25 M and the EOSDIS budget by $10.1 M, for a combined total of $775.1 M, with the express purpose of augmenting EOSDIS reserves and enhancing the funding for "secondary payloads," such as SAGE III and EOS Color.

More details concerning the status of the EOS Program appear in the *Mission Elements* section of this Handbook.

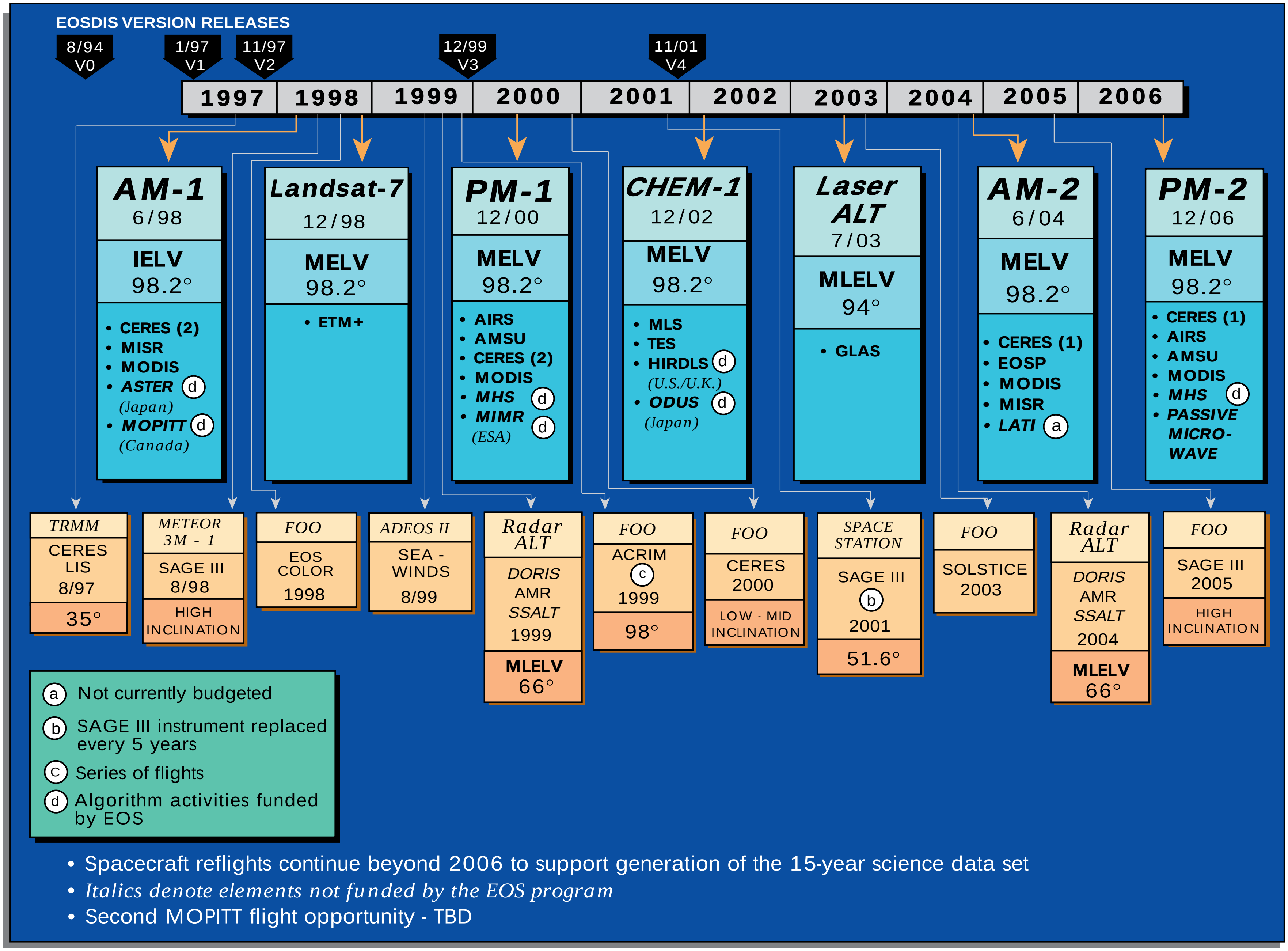


Figure 2. **EOS Mission Profile**

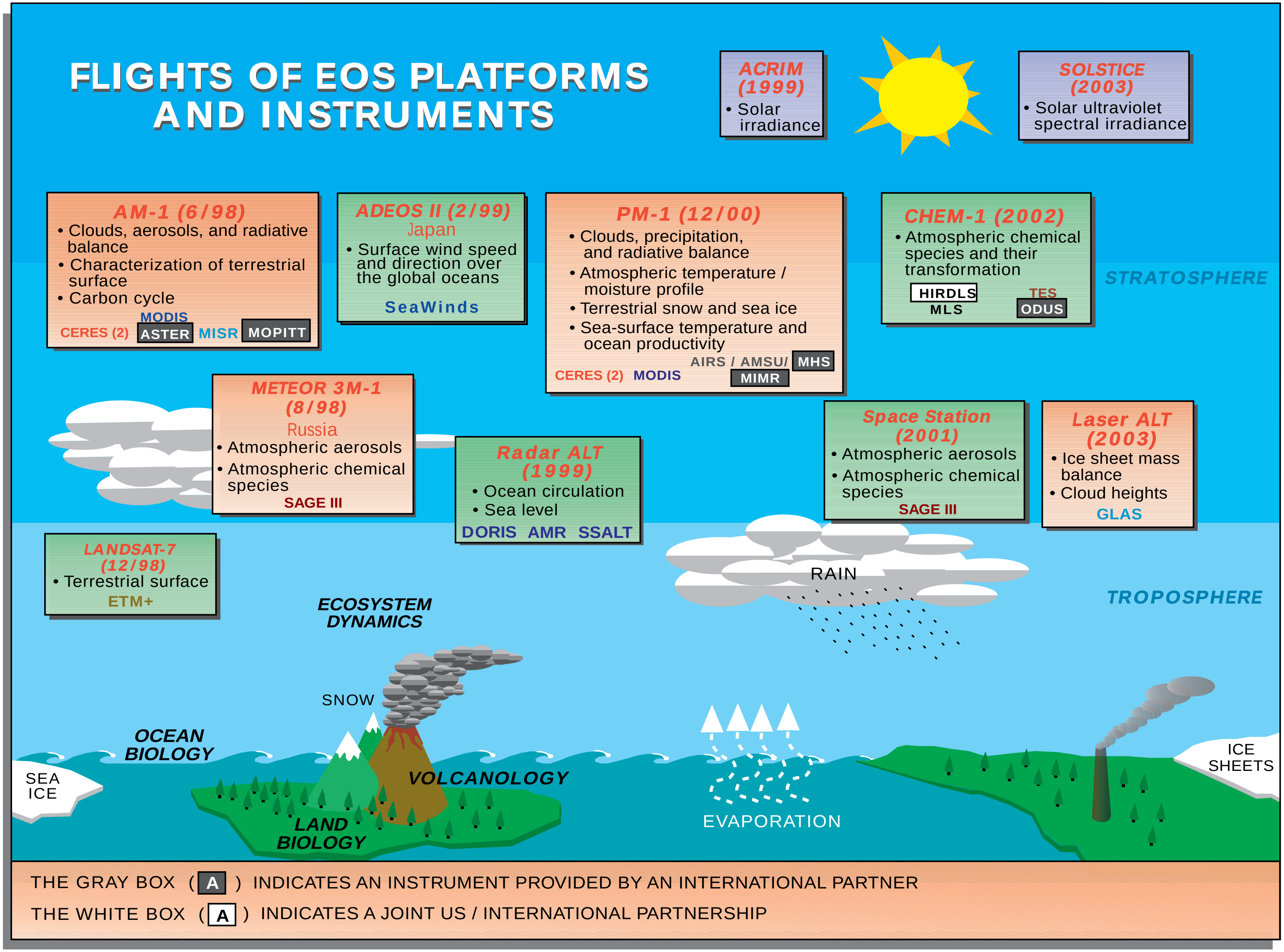


Figure 3. EOS Program Flight Elements

Launch	Spacecraft	Life-time	Instrument Complement	See Notes
1997	TRMM	3	CERES LIS	1
1998	Landsat-7	5	ETM+	
1998	EOS Color	3	Ocean Color Instrument *(under review)*	
1998	METEOR 3M-1	3	SAGE III	
1999	ADEOS II	5	SeaWinds	5
1999	ACRIMSAT	15	ACRIM	6
2001	Space Station	5	SAGE III	
1998	AM-1	6	MODIS MISR CERES (2) MOPITT ASTER	2,3
2004	AM-2	6	MODIS MISR CERES EOSP LATI	2,4
2010	AM-3	6	MODIS MISR CERES EOSP LATI	2,4
1999	Radar ALT-1	5	SSALT AMR DORIS	
2004	Radar ALT-2	5	SSALT AMR DORIS	
2009	Radar ALT-3	5	SSALT AMR DORIS	
2000	PM-1	6	MODIS MIMR CERES (2) AIRS AMSU MHS	2
2006	PM-2	6	MODIS Passive Microwave CERES AIRS AMSU MHS	2
2012	PM-3	6	MODIS Passive Microwave CERES AIRS AMSU MHS	2
2000	FOO	5	CERES	7
2003	FOO	3	SOLSTICE	
2005	FOO	3	SAGE III	
2002	CHEM-1	6	MLS TES HIRDLS ODUS	
2008	CHEM-2	6	MLS TES HIRDLS	
2014	CHEM-3	6	MLS TES HIRDLS	
2003	Laser ALT-1	3	GLAS	
2008	Laser ALT-2	3	GLAS	
2013	Laser ALT-3	3	GLAS	

NOTES:

1. TRMM is a joint U.S./Japan mission. It will also fly a Precipitation Radar (PR), TRMM Microwave Imager (TMI), and Visible Infrared Scanner (VIRS).

2. AIRS, AMSU, MHS, MIMR, and MODIS data available via direct broadcast (X band).

3. ASTER data available via direct downlink.

4. Landsat Advanced Technology Instrument (LATI) not currently funded.

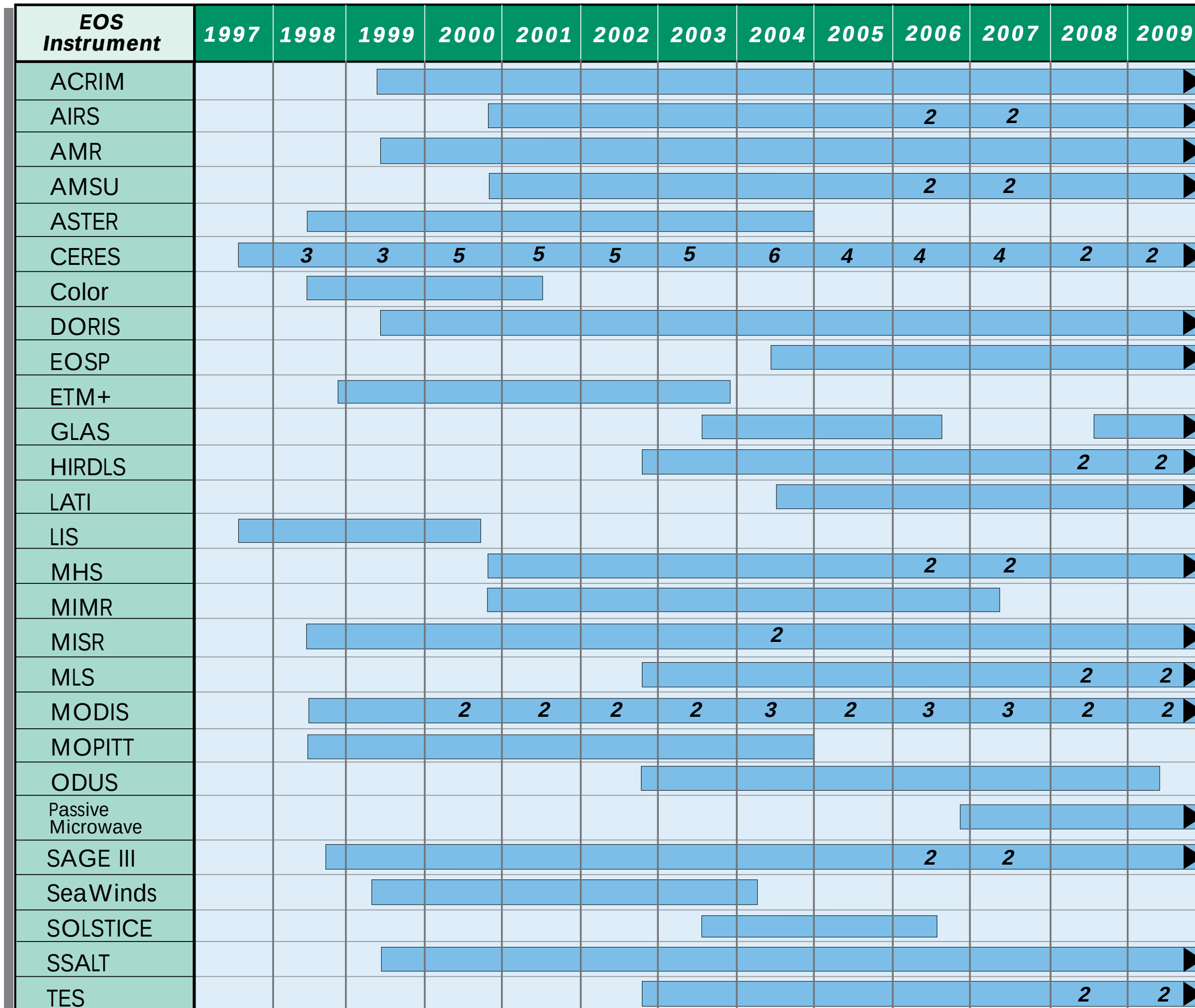
5. ADEOS II is a Japanese mission. It will also fly a Global Imager (GLI), and Advanced Microwave Scanning Radiometer (AMSR), and other instruments including POLDER and ILAS II.

6. Series of ACRIMSAT flights planned to maintain continuity in the solar irradiance data set for at least 15 years.

7. Flight of opportunity of CERES in a low-mid-inclination orbit.

Table 5. **Rebaselined EOS Program**

Table 6. **EOS Platform Instrument Counts and Data Rates**



	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Average Data Rate *(Mbps)*	0.016	30.8	30.8	38.4	38.4	41.4	41.6	46.4	28.8	36.2	36.2	32.2	32.2
Instruments In Flight	2	11	16	22	22	25	27	30	24	28	28	24	24

Platform Average Data Rates

- EOS AM-1 *17.626 Mbps*
- Landsat-7 *12.778 Mbps*
- EOS PM-1 *7.567 Mbps*
- EOS CHEM-1 *3.404 Mbps*
- FOO (Color) *0.347 Mbps*
- EOS Laser ALT Series *0.150 Mbps*
- Meteor 3M-1 (SAGE III) *0.024 Mbps*
- Space Station (SAGE III) Series *0.024 Mbps*
- FOO (SAGE III) *0.024 Mbps*
- ADEOS II (SeaWinds) *0.020 Mbps*
- TRMM (CERES & LIS) *0.016 Mbps*
- FOO (CERES) *0.010 Mbps*
- FOO (SOLSTICE) *0.005 Mbps*
- EOS Radar ALT Series *0.002 Mbps*
- ACRIMSAT Series *0.001 Mbps*

- Numbers in timeline bars indicate copies in orbit once the instruments have commenced routine operations
- The "Instruments in Flight" entry is the maximum number of instruments operating at the same time during the year. For example, there will be 6 CERES instruments operating during the last half of 2004 when the following missions overlap (there is a 6-month period of overlapping operation to permit instrument intercalibration): AM-1(2 CERES), FOO (1 CERES), PM-1 (2 CERES), and AM-2 (1 CERES). (See Figure 2.)

Contributions of MTPE and EOS to National Objectives

In pursuit of U.S. policy relative to global change, MTPE undertakes observations from space and performs interdisciplinary science studies to interpret and apply these observations. Integrated and conceptual models, substantiated by space-based observations, have already provided policy makers with a firm basis for making sound environmental policy decisions related to substances that deplete the ozone layer, e.g., the Montreal Protocol on Substances that Deplete the Ozone Layer (adopted in 1987). In the EOS era, the corresponding challenges include prediction of El Niño events, the implications of increased emissions of greenhouse gases for global warming, and impacts of land cover change on the carbon budget, biodiversity, and agricultural productivity. Fuller discussion of these challenges is found in the EOS Science Strategy document (see *References* at the end of this section).

A basic question that must be resolved before policy decisions can be reached has to do with determining whether changes now being observed throughout the world are systematic (relatively persistent long-term changes) or just part of normal climatic variability. If the changes being observed are in fact systematic, are they sufficiently significant in impact to warrant action by policy makers? Do we know well enough whether the observed changes are attributable to human activities? Are appropriate technological alternatives or restrictions on human activities available to mitigate the changes or their impacts, and is it reasonable to impose such restrictions? Are the consequences of imposing restrictions more damaging to our quality of life, e.g., because of major disruptions in the world's economy, than the anticipated changes in the global climate system?

The physical-modeling and data-gathering activities over the planned 15 or more years of the EOS Program are intended to make a major contribution to establishing the distinction between natural variability in the Earth system and changes that are introduced by human activities. The choices of intervention strategies to mitigate possible undesirable changes or their impacts will have to be based at least in part on the findings of MTPE- and EOS-supported scientists in the U.S. and their counterparts around the world.

MTPE offers a new perspective on the functioning of planet Earth through coordinated, long-term, space-based and *in situ* observations, and a program of interdisciplinary research addressing priority issues of Earth system science. This Presidential Initiative is supported by Congress, which granted NASA a "new start" budget line item for the EOS Program in 1990. Following this mandate from the Administration and Congress, NASA has placed itself at the forefront of Earth observing satellite technology development and data management. The improved measurement and modeling capabilities that result directly support the U.S. and international global change research programs, and reinforce the U.S. position as a world leader in space-based remote sensing.

The successive reconfigurations of the EOS payloads have had both benefits and pitfalls; yet, in the prevailing budget environment, decision makers have had to balance the science return against costs incurred. Any further rearrangements will require review by the EOS IWG to determine if they represent an acceptable solution towards satisfying the identified IPCC science and policy priorities (see Table 7). Furthermore, the potential of achieving the international commitments assumed in the rebaselined program must be quantified to determine the consequences of data gaps should these collaborations not be realized.

IPCC Category	EOS Instrument Complement
Sources and sinks of greenhouse gases, which affect predictions of their future concentrations	AIRS/AMSU/MHS, ASTER, HIRDLS, MIMR, MLS, MODIS, MOPITT, ODUS, SeaWinds, SAGE III, and TES
Clouds and radiative balance, which strongly influence the magnitude of climate change at global and regional scales	ACRIM, AIRS/AMSU/MHS, CERES, EOSP, MIMR, MISR, MODIS, and SOLSTICE
Oceans, which influence the timing and patterns of climate change	AMR, CERES, MIMR, MODIS, SeaWinds, and SSALT
Land surface hydrology, which affects regional climate change and water availability	AIRS/AMSU/MHS, ASTER, ETM+, LATI, MIMR, MISR, and MODIS
Polar ice sheets, which affect predictions of global sea level changes	AMR, GLAS, MIMR, and SSALT
Ecological dynamics, which is affected by, and responds to, climate change	AIRS/AMSU/MHS, ASTER, EOS Color, ETM+, LATI, MISR, and MODIS

Table 7. **Links to IPCC Areas of Uncertainty**

References

EOS—Science Strategy for the Earth Observing System, by Ghassem Asrar (EOS Program Scientist) and Jeff Dozier (University of California—Santa Barbara, former EOS Project Scientist), published by AIP Press, July 1994. This publication provides a broad overview of the EOS Program, stressing the scientific considerations that led to the definition of the overall program as an essential element of the U.S. Global Change Research Program (USGCRP).

Science Data Plan for the EOS Data and Information System, 1994, Matthew Schwaller and Brian Krupp, editors. Available from the EOS Library, Code 505, Goddard Space Flight Center. This publication describes the management approach as well as current and projected holdings of the EOS Data and Information System (EOSDIS) at the various Distributed Active Archive Centers around the United States.

The *EOSDIS Data Product Reference Handbook* (Volume 1 to be issued in 1995) provides high-level descriptions of the data sets that will be produced from instruments on the Tropical Rainfall Measuring Mission (TRMM) and EOS AM satellites. It highlights the significance, evolution, and application of the data products at a level intended for the general science public as well as for researchers. It will be available from Code 902, the Global Change Data Center, at the Goddard Space Flight Center.

Earth Observing System Output Data Products and Input Requirements, Version 3.0, April 1995. Available from the Code 505 Science Office, Earth Science Data and Information System, Goddard Space Flight Center. It lists all at-launch and post-launch data products planned by EOS instrument teams, gives information on the characteristics of each parameter, required input data, and processing load estimates.

The following two documents are in preparation: 1) *The EOS Contribution to National Goals* (edited by E. Barton, D. Hartmann, D. Schimel, and M. Schoeberl, and 2) the *EOS Science Implementation Plan*. Each is an intended product of the EOS In-

vestigators Working Group. The former will relate the activities, goals, and intended products of EOS to the requirements for the scientific insights needed for national policy making. The latter will be an in-depth presentation of the studies being conducted by the investigators, who form the scientific core of EOS. The nature of the scientific problems will be described; the plans for meeting these problems through acquisition of *in situ* and remote-sensing observations and through analyses will be given; and there will be expositions of the products that are anticipated as a result of the analyses.

The World Wide Web (WWW) is an excellent electronic source of EOS information. The following documents are currently available on the Web and others will be made available as they are published:

- *The Earth Observer* is a bimonthly newsletter of the EOS Project Science Office. It gives current reports on the status of various elements of the EOS Program. Issues dating back to November/ December 1992 are available on the Web.

- *Payload Panel Reports* are a key source of understanding the recommendations that have been made by this key group of EOS scientists for devising the payloads of the various EOS spacecraft missions that will best meet scientific and budgetary requirements of the Program.

- *Algorithm Theoretical Basis Documents (ATBDs)* are being developed for every EOS instrument standard product, although some ATBDs address more than one product, and some products are addressed by more than one ATBD. ATBDs typically provide the theoretical basis—both the physical theory and the mathematical procedures and possible assumptions being applied—for the calculations that have to be made to convert the radiances acquired by the instruments to geophysical quantities. The geophysical quantities are then available to the scientific community for studies of the various characteristics of the Earth system.

- The *EOS Directory* lists the addresses, affiliations, phone numbers, and electronic mail addresses, as well as assignments of EOS-related personnel.

In order to access these documents, use the following WWW location:
http://spso.gsfc.nasa.gov/spso_homepage.html

EOS Data and Information System (EOSDIS)

EOS Data and Information System (EOSDIS)

More than any other factor, the commitment to make Earth science data easily available to a wide community of users is critical to the success of NASA's Mission to Planet Earth. The EOS Data and Information System (EOSDIS) is being developed, with an initial version called Version 0 operating now to meet that commitment.

At present, EOSDIS manages data from NASA's past and current Earth science research satellites and field measurement programs, providing data archiving, distribution, and information management services. During the EOS era—beginning with the launch of the TRMM satellite in 1997—EOSDIS will command and control satellites and instruments, and will generate useful products from orbital observations. EOSDIS will also generate data sets made by assimilation of satellite and *in situ* observations into global climate models.

Services Provided by EOSDIS

EOSDIS is a comprehensive data and information system designed to perform a wide variety of functions in support of a heterogeneous national and international user community. To this end, EOSDIS provides a spectrum of services: some services are intended for a diversity of casual users, some are intended only for a select cadre of research scientists chosen by NASA's peer-reviewed competitions, and many fall somewhere in between these extremes. The primary services provided by EOSDIS are summarized below:

User Support—The vast majority of people who interact with EOSDIS will do so via the EOSDIS Distributed Active Archive Centers (DAACs). The functions of the DAACs are described in more detail in a following section, and details about each DAAC are provided in a subsequent section. The DAACs have User Support Services to assist users in data acquisition, search, access, and usage. While most of the interaction by users with EOSDIS is through human-computer interfaces, occasional consultation will be needed with the User Support Services staff for assistance with specialized questions regarding the data or the system. EOSDIS expects to provide support services to users from the public and private sectors, including research scientists, educators, students, users in public agencies responsible for operational applications such as weather forecasts and environmental monitoring, policy makers, and the public in general (see Table 8 for a listing of DAAC contact information).

Data Archive Management and Distribution—A list of current and projected EOSDIS data holdings is available in the EOSDIS Science Data Plan (see *References* at the end of this section). Overall, this list includes data products derived from the satellite missions and scientific campaigns, plus other related data and information. In the EOS era, EOSDIS will store all the standard and special products computed from the EOS instruments during the mission life, and distribute requested subsets to users either electronically (via networks) or on appropriate media. In addition, EOSDIS will store and distribute data from non-EOS sources that are needed for EOS standard product generation. Also, product generation algorithms, software, documentation, calibration data, engineering, and other ancillary data will be stored and provided to users upon request. Sufficient information will be stored about the system configuration history to be able to regenerate products in case of accidental or catastrophic loss.

Access to the current suite of EOSDIS data holdings may be obtained via the DAACs.

Information Management—EOSDIS provides convenient mechanisms for locating and accessing (either electronically or via orders for data on media) subsets of products of interest. The "look and feel" of the system is intuitive, and uniform across the multiple nodes from which EOSDIS will be accessed. EOSDIS will facilitate collaborative science by providing extensible sets of tools and capabilities such that investigators may provide access to special products (or research products) from their own computing facilities. EOSDIS has a currently operational "Version 0 Information Management System" (V0 IMS) that provides "one-stop-shopping" access to the data holdings at all the EOSDIS DAACs. The V0 IMS permits users with properly configured workstations and personal computers to access EOSDIS archives, browse data holdings, select data products, and place data orders. Users who wish to employ the V0 IMS may do so by contacting DAAC User Services for more information (see Table 8). Alternatively, the latest information about the features of and access to Version 0, and links to information about individual DAACs, is available through the following World Wide Web location:

http://harp.gsfc.nasa.gov:1729/eosdis_documents/eosdis_home.html

Product Generation—Beginning with the TRMM launch in 1997, EOSDIS will support data product generation from EOS instrument observations. Algorithms and software for EOS data products are generated by EOS investigators as a part of their scientific studies. Specifications for standard products are reviewed by NASA and the EOS Investigators Working Group (IWG) to ensure completeness and consistency to satisfy the goals of the EOS mission. The physical, chemical, and biological bases for these products and soundness of approach for their generation are peer reviewed independently by non-EOS Earth scientists prior to the launch of each instrument. Priorities for the processing and reprocessing needed to generate standard products depend on scientific requirements, technical considerations, and cost. Such priorities are determined by the EOS Program and Project Scientists based on recommendations from the IWG and the national and international Earth science community.

Spacecraft Command and Control—EOSDIS will perform spacecraft and instrument planning and scheduling and command and control. These functions include processing data acquisition requests, coordination of multi-instrument observations, ensuring that the commands generated are valid and within resource constraints, monitoring and maintenance of the health and safety of spacecraft and instruments, engineering analysis of spacecraft data, and maintaining history of spacecraft and instrument operations. EOSDIS will also provide appropriate interfaces to ensure command and control of International Partners' instruments on-board EOS spacecraft, and EOS instruments on-board non-EOS spacecraft.

Data Capture and Telemetry Processing—In the EOS era, EOSDIS will capture data from all EOS spacecraft and process them to remove telemetry errors, eliminate any artifacts, and create Level 0 data products that are "raw" data as measured by the instruments (see the end of this section for data level definitions). Several of the EOS instruments are designated as prototype operational environmental monitoring instruments. The data from those instruments will be made available to NOAA within three hours of observation to support operational weather forecasts. For EOS instruments flying on non-EOS spacecraft, the EOS instrument data are captured by the respective ground systems and received by EOSDIS for higher-level data processing, archiving, and distribution.

EOSDIS Components

NASA is implementing EOSDIS using a distributed, open system architecture. This permits the allocation of EOSDIS elements to various locations to take best advantage of different institutional capabilities and science expertise. EOSDIS will consist of an EOSDIS Core System (ECS) to provide centralized mission and instrument command and control functions, and distributed (but common) product generation, archiving, and information management functions. Capabilities also exist outside of the core, including site-unique extensions to core capabilities, computing facilities for EOS researchers, and so on. Although EOSDIS is physically distributed, its components will be integrated so that they appear as a single logical entity to users.

Table 8. EOS Distributed Active Archive Centers

DAAC & DISCIPLINE	ADDRESS	CONTACT INFORMATION
ASF Sea Ice, Polar Processor Imagery (SAR)	Alaska SAR Facility, GeoData Center Geophysical Institute - GeoData Center University of Alaska Fairbanks, AK 99775-7320	*USER SUPPORT OFFICE CONTACT:* Greta Reynolds *INTERNET:* usa@santa.asf.alaska.edu *TEL:* (907) 474-6166 *FAX:* (907) 474-5195 *URL:* http://eosims.asf.alaska.edu:12355/datacenters_documents/ASF_datacenter_doc.html
CIESIN Consortium for International Earth Science Information Network	Socioeconomic Data and Applications Center 2250 Pierce Road University Center, MI 48710	*USER SUPPORT OFFICE CONTACT:* Richard Robinson *INTERNET:* ciesin.info@ciesin.org *TEL:* (517) 797-2727 *FAX:* (517) 797-2622 *URL:* http://www.ciesin.org
EDC Land Processes Data	United States Geological Survey EROS Data Center Sioux Falls, SD 57198	*USER SUPPORT OFFICE CONTACT:* Steve Johnson *INTERNET:* sjohnson@edcserver1.cr.usgs.gov *TEL:* (605) 594-6116 *URL:* http://sun1.cr.usgs.gov/landdaac/landdaac.html
GSFC Upper Atmosphere, Atmospheric Dynamics, Global Biosphere, Geophysics	NASA/Goddard Space Flight Center Code 902.2 Greenbelt, MD 20771	*USER SUPPORT OFFICE CONTACT:* Jim Closs *INTERNET:* daacuso@daac.gsfc.nasa.gov *TEL:* (301) 286-3209 *FAX:* (301) 286-1775 *URL:* http://daac.gsfc.nasa.gov/DAAC_DOCS/gdaac_home.html
JPL Ocean Circulation and Air-Sea Interaction	Jet Propulsion Laboratory MS 300-320 4800 Oak Grove Drive Pasadena, CA 91109	*USER SUPPORT OFFICE CONTACT:* Susan Digby *INTERNET:* podaac@podaac.jpl.nasa.gov jpl@eos.nasa.gov *TEL:* (818) 354-9890 *FAX:* (818) 393-2718 *URL:* http://seazar.jpl.nasa.gov/
LaRC Radiation Budget, Clouds, Aerosols, Tropospheric Chemistry	NASA/Langley Research Center Mail Stop 157B Hampton, VA 23681-0001	*USER SUPPORT OFFICE CONTACT:* User Services Office *INTERNET:* userserv@eosdis.larc.nasa.gov *TEL:* (804) 864-8656 *FAX:* (804) 864-8807 *URL:* http://eosdis.larc.nasa.gov/
MSFC Hydrologic Cycle	NASA/Marshall Space Flight Center DAAC User Services Office 977 Explorer Boulevard Huntsville, AL 35806	*USER SUPPORT OFFICE CONTACT:* Dawn Conway *INTERNET:* msfc@eos.nasa.gov *TEL:* (205) 922-5932 *FAX:* (205) 922-5859 *URL:* http://wwwdaac.msfc.nasa.gov/
NSIDC Snow and Ice, Cryosphere and Climate	National Snow and Ice Data Center CIRES, Campus Box 449 University of Colorado Boulder, CO 80309-0449	*USER SUPPORT OFFICE CONTACT:* NSIDC User Services *INTERNET:* nsidc@eos.nasa.gov nsidc@kryos.colorado.edu *TEL:* (303) 492-6199 *FAX:* (303) 492-2468 *URL:* http://eosims.colorado.edu:1733
OAK RIDGE Biogeochemical Dynamics	Oak Ridge National Laboratory (ORNL) Environmental Sciences Division P. O. Box 2008, MS 6407 Oak Ridge, TN 37831-6407	*USER SUPPORT OFFICE CONTACT:* Merilyn J. Gentry, Jerry W. Curry *INTERNET:* ornldaac@ornl.gov *TEL:* (615) 241-3952 *FAX:* (615) 574-4665 *URL:* http://www.eosdis.ornl.gov

As illustrated in Figure 4, the EOSDIS architecture is composed of several types of elements, most of which will be geographically distributed, thereby providing a resilient program. The following paragraphs provide details on each of the major components making up the data system. This presentation should not be considered a prioritized ranking; rather, each component proves invaluable in the successful implementation of EOSDIS.

Distributed Active Archive Centers (DAACs)—Eight DAACs representing a wide range of Earth science disciplines have been selected by NASA to carry out the responsibilities for processing, archiving, and distributing EOS and related data, and for providing a full range of user support. A ninth DAAC acts as a link between the EOS Program and the socio-economic and educational user community. The geographic distribution of the DAACs is illustrated in Figure 5. These institutions are custodians of EOS mission data, and ensure that data will be easily accessible to users. Acting in concert, DAACs provide reliable, robust services to users whose needs may cross traditional discipline boundaries, while continuing to support the particular needs of their respective discipline communities. DAAC assignments were based primarily on the current distribution of scientific expertise, institutional heritage, and capability. The DAACs provide their services to the user community, using capabilities developed as a part of the Science Data Processing Segment of the EOSDIS Core System (see subsection below) and may develop unique capabilities to augment them. Each DAAC has a working group of users to provide advice on priorities for scientific data, levels of service, and the needed capabilities. The DAACs actively participate in the design, implementation, and operation of EOSDIS.

Scientific Computing Facilities (SCFs)—Computing facilities used by the EOS investigators (Facility Instrument Team Leaders and Team Members, Instrument Principal Investigators, and Interdisciplinary Investigators) are called SCFs. These facilities range from individual workstations to supercomputers. They are used to develop algorithms and models for the generation of standard and special products, to access services in EOSDIS, to conduct scientific research, to generate four-dimensional data assimilation and, in some cases, to provide a subset of EOSDIS services to the user community. Some of the SCFs, collocated with investigators responsible for standard products, are designated Quality Control (QC) SCFs. These are used for performing scientific quality control of the data products. Some SCFs support the planning, scheduling, command and control, and analysis of instrument engineering data.

EOSDIS Core System (ECS)—ECS provides the "core" common capabilities and infrastructure required for performing planning and scheduling, command and control, product generation, information management, data archiving and distribution, and user access to data held by EOSDIS. ECS consists of three segments described below: the Science Data Processing Segment, the Flight Operations Segment, and the Communications and System Management Segment.

- **Science Data Processing Segment (SDPS)**—SDPS supports product generation, data archiving and distribution, and information management. The SDPS hardware and software, developed as a part of ECS, will reside and operate at the DAACs. SDPS supports the integration and testing of software for product generation algorithms developed by the EOS investigators. It provides for planning of data product generation, taking into account interdependencies among them, and the distribution of computational resources. It provides for ingest and storage (temporary or permanent, depending on data type) of data sets needed from other data centers for supporting the generation of standard data products. It generates standard products in a timely manner using the investigator-provided software. It supports the extraction of appropriate subsets of standard data products to assist in scientific quality control by the respective investigators. It supports reprocessing as required.

- **Flight Operations Segment (FOS)**—FOS controls all of the EOS spacecraft, provides mission planning and scheduling, and monitors health and safety of the spacecraft and instruments. It provides tools to coordinate observations from multiple instruments and develop conflict-free schedules, validate commands to assure safety, accommodate unplanned schedule changes, develop and provide mission timelines, and develop and

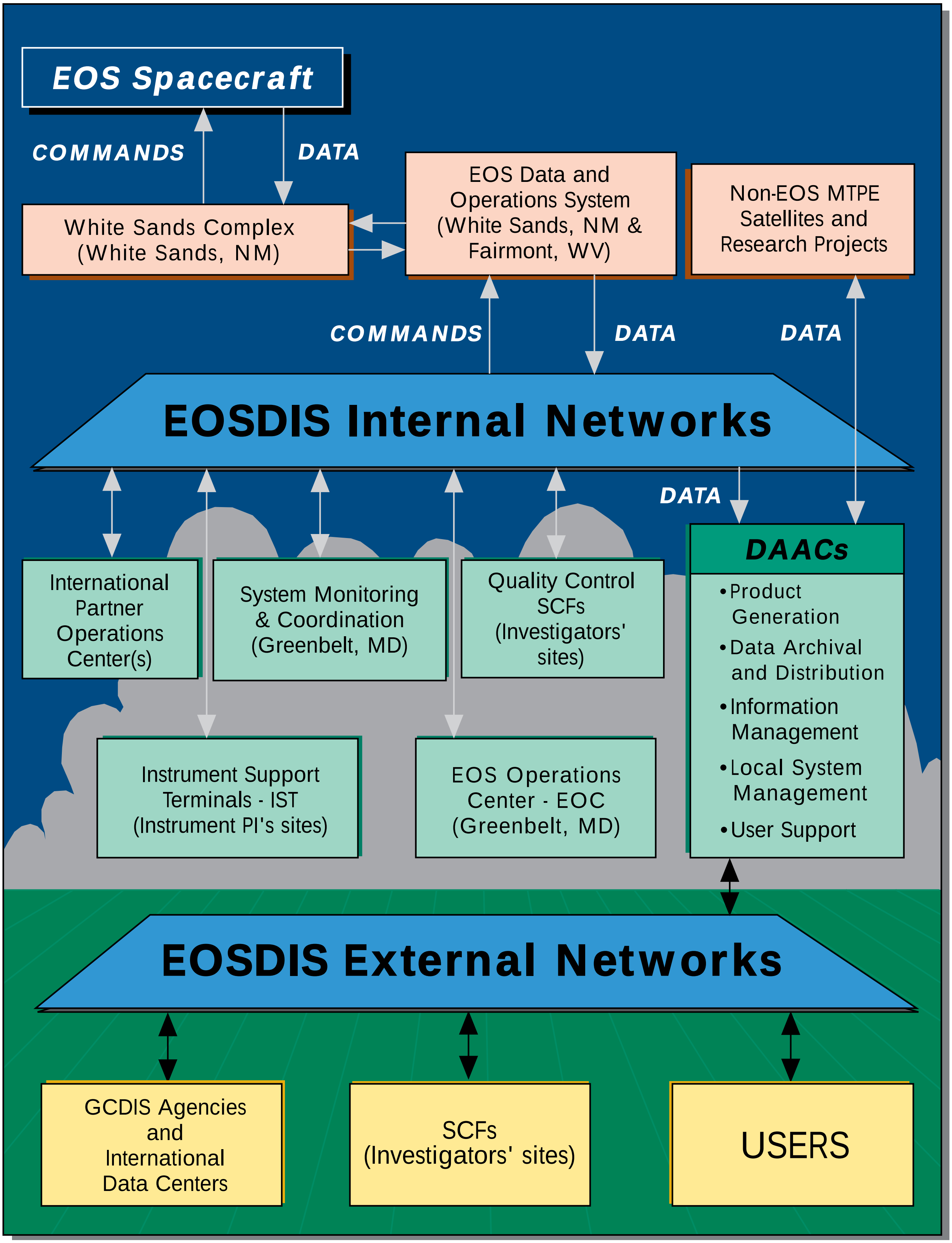


Figure 4. **EOSDIS Architecture**

implement contingency plans. It interacts with the various elements of the ground systems and space network as necessary to send commands to the EOS spacecraft and to receive health and safety data from the spacecraft. It interacts with the International Partners' instrument control centers for exchange of planning and command and control information.

- **Communications and System Management Segment (CSMS)**—CSMS provides the communications, networking, and system management functions needed by the SDPS and FOS. It provides the capabilities for the DAACs to perform local system management functions and the capabilities for cross-DAAC coordination and monitoring to ensure autonomous, yet coordinated operation of SDPS. It provides for monitoring and maintaining status information about EOSDIS. It provides common services such as object request brokering, client/server communications, electronic mail, bulletin boards, local area and wide area networks, system security, accounting, user registration, and report generation.

EOS Data and Operations System (EDOS)—EDOS transmits commands to the EOS spacecraft, captures science and engineering data from the spacecraft and instruments, processes telemetry to generate Level 0 products, and maintains a backup archive of Level 0 products. It removes telemetry artifacts, creates sets of non-overlapping raw data as sensed by the individual instruments over specific time intervals, and sends them to the appropriate DAACs for generation of higher level products. In the case of a data loss at any of the DAACs, the data can be recovered from the backup archive within EDOS. In the case of loss of a part of the backup Level 0 data within EDOS, the corresponding data can be recovered from the appropriate DAAC.

EOS Networks—Effective access to EOSDIS depends on network connectivity between users and data sources. Existing and evolving network capabilities in the U.S. and abroad will be used to satisfy the connectivity needs. These capabilities include the NASA Science Internet, its connections to the National Science Foundation (NSF) Internet, and the

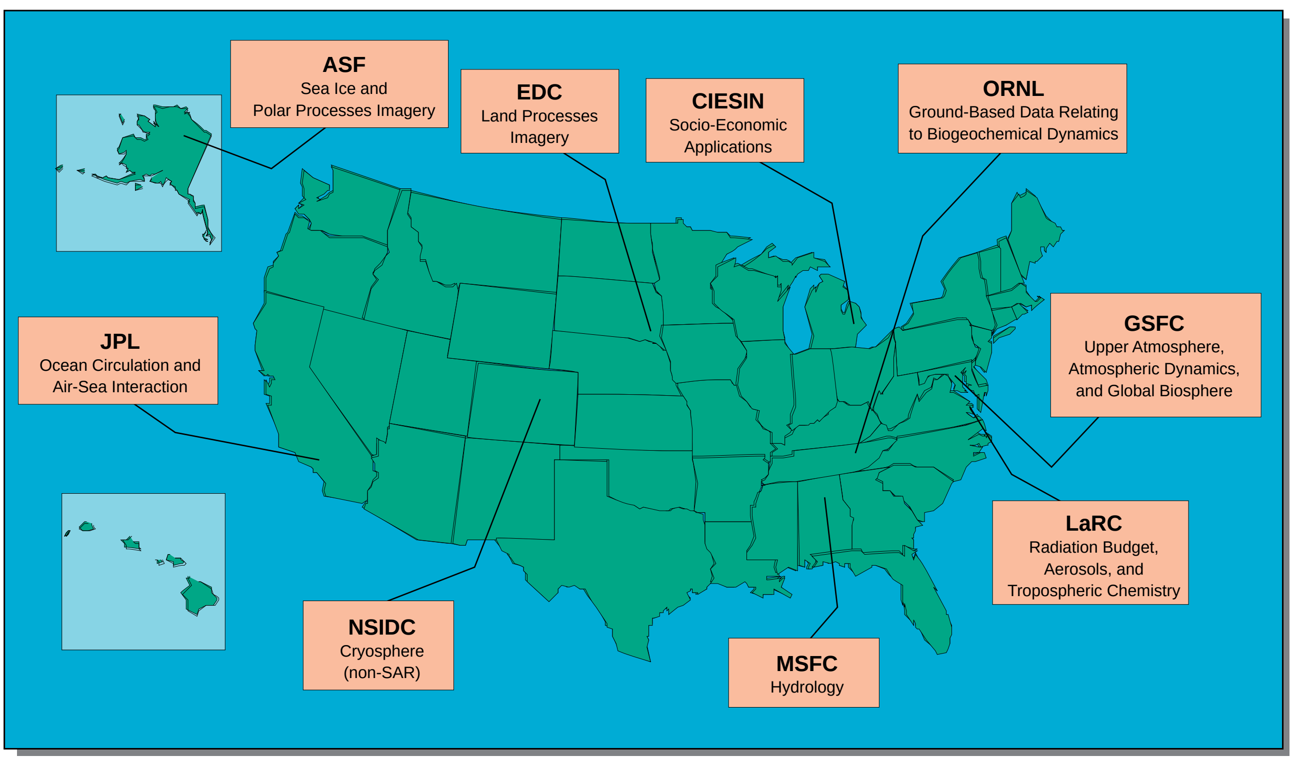


Figure 5. **Geographic Distribution of EOSDIS**

National Research and Education Network (NREN) as it develops. Connectivity to the EOS investigators' computing facilities (SCFs) is being established, based on existing connectivity and need. The SCFs that are involved in the quality control of standard data products will be provided the appropriate connectivity to ensure timely data transfers to meet their requirements. The DAACs, ECS, and EDOS are connected through the EOSDIS Internal Network to assure security, timeliness, and predictable response. The EOSDIS Internal Network currently consists of the "Version 0 Network" that interconnects the DAACs as a prototype. The inter-DAAC network will be upgraded in the EOS era to meet EOS product generation needs. Another part of the EOSDIS Internal Network under development is called EOS Communications (Ecom). The major functions of Ecom are to provide secure, reliable communications to uplink commands to the EOS spacecraft and to move Level 0 instrument data to the DAACs.

EOSDIS Architecture and Evolution

Since EOSDIS will be NASA's Earth science data system for at least the next two decades, it must evolve to accommodate changes in technology, user requirements, and user interactions with data and data systems. To reach this end, EOSDIS planning has been significantly influenced by reviews from the EOSDIS Panel and the National Research Council Panel to review EOSDIS Plans. Some of the key science goals in the design of the system have been the need to support data search and access, dynamic product life cycle and extensible product sets, interactive investigations, information-rich logical data collections, integration of independently developed investigators' tools and software, user-to-user collaboration, distributed administration and control, and site autonomy.

To reach its joint goals for science support and evolution, EOSDIS is designed as a logically distributed system. It will have sufficient modularity and standard interfaces to enable migration and/or replacement of components. It will be built with a selection of subsystems and services tailored to particular data types and other specific needs. It will permit autonomy for service providers and the required amount of coordination among them.

A basic feature of the EOSDIS architecture is its reliance on the "client-server" model. A client is a process that requests a service. A server provides the requested service. Some servers, called "agents," may call upon other servers while processing a client's request. The EOSDIS architecture permits easy introduction of new technologies and addition of servers that may provide subsets of the services offered by EOSDIS. Such servers are not necessarily designed, built, or provided by the EOS Program. It is important to note, however, that non-EOS data servers will still be able to interact with EOSDIS.

Some of the key features of the distributed EOSDIS architecture are provided below. Greater detail on the EOSDIS architecture can be found in the references at the end of this section.

Advertising Service—Each component of EOSDIS advertises the availability of its services. Users can query and browse advertisements to find services of interest to them. This service may also be used by service providers external to ECS to make their services known to other users.

Universal References —A consistent and uniform format called the Universal Reference format is used for internal interaction among services. The Universal Reference is supported by all the SDPS subsystems discussed below. It supports multiple formats all of which carry equivalent information, e.g., a C++ data structure and an ASCII string. It facilitates user readable references, e.g., icons, for external representation of services while providing a standard for internal communication.

Service Classes—The services and data offered by a given system component are accessed via defined "service interfaces." The services are grouped into "service classes," and each service class has a defined interface that can be accessed locally or remotely.

Application Programming Interfaces (APIs)—For the interoperation of software components with each other, each of the services defines an API called the Client API. Programs call the Client API to obtain a service. The CSMS provides services needed for the software components to communicate with each other. Both the definition of service classes and APIs provide modularity in the system. They facilitate integration of independently developed components into EOSDIS or migration of components of

EOSDIS to external providers' systems.

Data Collections and Data Servers—The Earth science data are organized in collections of related data. Each collection is managed by a data server. The data servers can be tailored to the data types, thus permitting different designs and organizations of data depending, for example, on whether the data are multispectral images or atmospheric soundings. The physical location of the data collections is transparent to users.

Data Production—The functions in the system used for product generation are treated like any other service. The site that offers the service advertises it and can be found regardless of its location. Distributed planning permits making optimal use of distributed computing resources. The design also permits flexibility in decisions on whether a product should be produced routinely or on-demand, and whether it should be produced at a DAAC or SCF.

Data Ingest—The data ingest service is distributed such that data can be ingested routinely or ad hoc. The ingest services can be found through the advertising service and contacted via the CSMS without regard to their location.

Data Search and Access—The search and access services are found through the advertising service. Users can issue search and access requests directly to the data servers, or use a distributed search service to find data from multiple data collections and combine the results. The distributed information management across multiple sites and the local information management for a given site are provided as separate services to provide sites with autonomy in making changes to their local components.

User needs for EOSDIS will become more clearly understood as researchers work with, and respond to, early versions of the system; user needs will undoubtedly change over time. New information systems technology will emerge continually, including new data base and information management technology applicable to Earth science data, faster processors, and more-capable networks. To succeed over its lifetime, EOSDIS must respond to change; its design and the implementation process must foster change while supporting ongoing operations and user services. Development and prototyping will continue throughout the life of the system. EOSDIS evolution begins with V0, and will continue with subsequent versions as described below.

EOSDIS V0—A working prototype with some operational elements, this initial version of EOSDIS interconnects existing Earth science data systems via electronic networks, interoperable catalogs, and common data distribution procedures to provide better access to existing and pre-EOS data. Starting with existing, heterogeneous Earth science data systems, V0 will evolve toward the full EOSDIS by taking maximum advantage of existing experience and by ensuring that no disruption in current user services occurs. Through the interconnection of the existing systems, V0 serves as a functional prototype of selected key EOSDIS services. As a prototype, it does not have all the capabilities, fault tolerance, or reliability of the later versions; however, EOSDIS V0 supports use by the scientific community in day-to-day research activities. Such use tests existing services to determine the additional or alternative capabilities required of the full EOSDIS. Development of V0 began in 1991 as a collaborative effort between the Earth Science Data and Information System (ESDIS) Project, all the DAACs, and the NOAA Satellite Active Archive (SAA). V0 became operational in August 1994.

EOSDIS V1—Version 1, planned for release in January 1997, will provide full support for TRMM. This support will include product generation from the EOS instruments (CERES and LIS) and archiving and distribution of data products resulting from all TRMM instruments. Version 1 supports the early testing of EOS AM-1 spacecraft command and control, and the testing of interfaces between the FOS, EDOS, Ecom, and the NASA institutional capabilities supporting EOSDIS. For providing users with uninterrupted access to data and information, Version 0 and Version 1 will operate in parallel until the data from Version 0 are migrated into the Version 1 system and the Version 0 hardware components become obsolete. During this period, the two systems will interoperate.

EOSDIS V2—Version 2, planned for release in October 1997, will provide the full functionality of the system and the services discussed in the sections above on major components and architecture. The Data Management Subsystem of the SDPS will be fully implemented to permit cross-site coincident searches. It will be the "launch-ready" version for EOS AM-1, Color, and Landsat-7. It will support pre-launch testing for these flights and the operations after the launches occur. It will also provide interim support for SeaWinds, Radar Altimetry, and ACRIM. An increase in capacity is planned for September 1998 to provide full support for these flights.

Subsequent versions of EOSDIS will supplement capacity and services as required by EOS spacecraft launches. EOSDIS capabilities will evolve based on continuing evaluation by the research community, and technology will be enhanced as the need arises.

At the end of the EOS mission, plans call for the data held by EOSDIS to be transferred to the control of long-term archival agencies that have vested interest and responsibility for management and distribution of such data. Examples include, but are not limited to, the Department of Energy, NOAA, and the U.S. Geological Survey (USGS).

Key EOSDIS Terminology

Standard Data Products—Data products that are generated as part of a research investigation using EOS data, are of wide research utility, are routinely generated, 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 Science 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 continually by the EOS 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 at the DAACs.

Special Data Products—Data products that are generated as part of a research investigation using EOS data, and that are produced for a limited region or time period, or products that are not accepted as standard by the EOS IWG and NASA Headquarters, are referred to as special data products. Special data products will normally be generated at investigator SCFs. Upon review and approval by independent peer review, EOS IWG, and NASA Headquarters, special products may be reclassified later as standard products; in which case, the algorithms and processing will migrate to the DAACs 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 EOSDIS Data Panel in its report, and are consistent with the Committee on Data Management, Archiving, and Computing (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. Brief definitions follow:

Level 0—Reconstructed, unprocessed instrument/payload data at full resolution; any and all communications artifacts, e.g., synchronization frames, communications headers, duplicate data removed.

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, e.g., platform ephemeris, computed and appended but not applied to the Level 0 data.

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

Level 2—Derived geophysical variables at the same resolution and location as the Level 1 source data.

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

Level 4—Model output or results from analyses of lower level data, e.g., variables derived from multiple measurements.

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National Research Council, 1994: Panel to Review EOSDIS Plans: Final Report, *National Academy Press*, Washington, DC.

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Data and Information Policy

Data and Information Policy

The MTPE/EOS data policy is designed to be consistent with the U.S. data exchange principles for global change research and to further the EOS objectives of acquiring a comprehensive global, long-term data set; maximizing data utility for scientific purposes; and simplifying access to and analysis of EOS data. A common set of data exchange principles covers the Japanese, European, and U.S. missions composing IEOS (see the *International Cooperation* and *Mission Elements* sections). In realizing this goal, NASA has adopted the following data policy:

- Data from EOS instruments will be acquired according to priorities recommended by the IWG and the EO-ICWG, and confirmed by NASA Headquarters.

- Where EOS sensors make site-specific observations, EOS will be an "acquire-on-demand" system. Data will only be taken in cases where there is an identified user who has requested and will analyze the data.

- All acquired EOS data will be processed at 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 as soon as they are received on the ground.

- Routine processing and reprocessing of EOS data by the ESDIS Project to standard products at Levels 2 and above will be done according to science requirements and using algorithms approved through peer review and by the IWG.

- EOS data and products will be available to all users; there will be no period of exclusive access.

- For data from U.S. sources, all data will be made available consistent with Office of Management and Budget (OMB) Circular A-130, without restriction, at not more than the cost of dissemination, without regard to intended use. Circular A-130, "Management of Federal Information Resources," states that the government can charge the public for the cost of data dissemination, but not for data collection. Circular A-130 also gives individual agencies the right to charge less than the cost of dissemination, if the true cost inhibits the use of the data.

- For data from partner agencies, all data requests for approved research, non-commercial operational, and applications demonstration purposes will incur a modest charge consistent with the actual marginal costs of filling the request. Data will be provided for other uses, including commercial activities, on the same time scales and at non-discriminatory prices and terms to be established by the relevant instrument provider and platform operator.

- ESDIS will include and make available information about the data, such as quality assessments, supporting literature references, and catalog and directory entries.

- ESDIS project management, in consultation with the IWG, will establish protocols and standards to encourage and facilitate data and software exchange and interoperability.

The data collected by EOS represent a significant public investment in research. NASA holds this data in public trust to promote comprehensive, long-term Earth science research. Consequently, NASA developed a policy, consistent with existing national and international policies, to maximize access to data and to keep user costs low. The policy applies to all data archived, maintained, distributed, or produced by EOSDIS. In this context, the term "data" includes data, metadata, products, information, algorithms, documentation, models, images, research results, etc.

All users will have complete access to all EOS data. Aside from a three-month measurement calibration and algorithm testing period after launch, no data from an EOS satellite or instrument will have a period of exclusive access. Any variation in access will result solely from user capability, equipment, and connectivity.

EOS has made many agreements with other Federal agencies and international partners for the exchange of data. For data products supplied from an international partner or another agency, EOSDIS will restrict access only to the extent required by the appropriate Memorandum of Understanding. Completed and anticipated international agreements ensure that data for research, applications, demonstrations, and non-commercial operational use for the public benefit will be provided at the lowest possible cost. The only area remaining to be finally defined is whether there will be any additional or different terms and conditions for other categories of use (including commercial). If such different approaches are required for data from programs funded by partner organizations, they will be applied on a nondiscriminatory basis to all users in that category, regardless of nationality. For data products purchased from a private corporation, organization, or vendor, EOSDIS will restrict access in accordance with the licensing agreement. In all cases, NASA will negotiate such agreements to assure as broad an access to data as possible.

In keeping with OMB Circular A-130, EOSDIS will charge users not more than the costs of fulfilling an order. The cost of fulfilling an order may include machine use to execute searches, to stage data for electronic or media delivery, and to perform any unique processing of the data. EOSDIS may also charge for packaging and media used for data delivery. EOSDIS will not charge for the institutional costs of a DAAC, such as utilities, facility maintenance, and management. EOSDIS will not charge users for the archival, storage, and documentation of the data. EOSDIS will not charge users for the costs of routine product generation. Users may pay shipping and network transmission costs. To promote the use of EOSDIS, first-time users will receive a credit balance. Only after a user spends this credit will EOSDIS start charging. NASA will work out the pricing details well before the launch of TRMM and the release of EOSDIS Version 1.

EOSDIS will consistently apply this pricing policy to all users and will not discriminate in price based on the user or the data application for data from NASA sources. For data products supplied by an international partner or another agency, EOSDIS will apply the agreed terms in the relevant Memorandum of Understanding. EOSDIS will not sell data products for a private corporation, organization, or vendor.

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Pathfinder Data Sets

Pathfinder Data Sets

The Pathfinder data set concept was initiated by the EOS Program Office at NASA Headquarters in answer to the question "What can be done now to further global change research?" Pathfinders provide access to large remote-sensing data sets applicable to global change research prior to the availability of data from the EOS satellites. From these long-time series of global and/or regional data sets, higher level geophysical products are derived in support of USGCRP objectives. The main goal of the Pathfinder Program is to make research-quality global change data sets easily available to the Earth science community. Of course, experience gained in processing/reprocessing, archiving, and distributing standard scientific data products proves a boon as well. As scientific understanding develops and product retrieval algorithms are improved, these data sets may require additional reprocessing, which would be provided by this program.

All Pathfinder data sets involve space-based observations, and are subject to the following requirements: 1) stable calibration of the raw data should be attainable; 2) when data from multiple instruments are involved, consistent intercalibration among instruments in a series should be possible; and 3) archiving may include transferring the data to a more-accessible medium. The resultant data sets are available at responsible DAACs, and through EOSDIS Version 0.

A benchmark period (April 1987 to November 1988) was chosen to facilitate complementary analyses and intercomparison studies. Wherever possible or applicable, Pathfinder data processing began with this time period.

In October 1990, NOAA and NASA signed an agreement establishing three joint NASA/NOAA Pathfinders to be generated from existing NOAA data sets, as follow:

- Advanced Very High-Resolution Radiometer (AVHRR) Global Area Coverage (GAC) data held by NOAA.
- Television and Infrared Observation Satellite (TIROS) Operational Vertical Sounder (TOVS) data held jointly by NOAA and NASA.
- Geostationary Operational Environmental Satellite (GOES) data held by the University of Wisconsin under contract with NOAA.

In 1991, the Special Sensor Microwave/Imager (SSM/I) data set was added as a NASA/NOAA Pathfinder. SSM/I data are currently archived by NOAA under a Shared Processing Agreement with the Navy and the Air Force.

Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) data held primarily by USGS/EDC were added to the Pathfinder activity in 1992. The Landsat Pathfinder effort involves NASA, EPA, and USGS. Also in 1992, NASA's Scanning Multispectral Microwave Radiometer (SMMR) data set was added as the first NASA-only Pathfinder.

One or more Science Working Groups (SWGs) have been formed for each of the identified interagency data sets to provide recommendations for specific Pathfinder activities. SWG reports to the involved partner agencies consist of the following:

- Determination of the scientific needs for Pathfinder data and how these needs translate into specific products.

- Identification of community-consensus algorithms for generating Pathfinder products and determination of the data required to generate these products.

- Recommendation on how these products are to be generated, validated, stored, and maintained.

- Identification of the data services required by users of Pathfinder data (including catalog and browse functions, metadata, and data access).

Initial Pathfinder reprocessing of these data sets is currently complete or being completed using community-consensus algorithms as recommended by designated SWGs or a similar process.

Pathfinder data products are treated as new data sets and are archived at one or more EOSDIS DAACs according to discipline responsibilities. Copies may also be archived by the collaborating agencies. Table 9 lists the current Pathfinder efforts and the DAACs currently planning to house the reprocessed data.

Data Set	DAAC (Discipline Focus)
AVHRR Advanced Very High-Resolution Radiometer	**GSFC** *(Atmosphere, Land)* JPL *(Ocean)*
TOVS TIROS Operational Vertical Sounder	GSFC *(Atmosphere)*
GOES Geostationary Operational Environmental Satellite	University of Wisconsin LaRC *(Clouds and Radiation)*
SSM/I Special Sensor Microwave/Imager	MSFC *(Hydrology)* JPL *(Ocean)* NSIDC *(Cryosphere)*
SMMR Scanning Multispectral Microwave Radiometer	MSFC *(Hydrology)* JPL *(Ocean)* NSIDC *(Cryosphere)*
Landsat Land Remote-Sensing Satellite	EDC *(Land)*

Table 9. **Pathfinder Data Availability**

AVHRR Pathfinder scientific data products consist of global vegetation and radiance data products over land, global sea-surface temperature data products over the ocean, and global clouds, radiation, and aerosols data products for the atmosphere. These data are produced from GAC observations made by the five-channel AVHRR instruments onboard NOAA-7/9/11/14, and will cover the time period of mid-1981 through 1992 and beyond. Processing of land and ocean products began in 1993 and 1994 respectively. Multiple years of data products are now available, with the entire time-series of both scheduled for completion in early 1996. Atmosphere product processing, supported by NOAA, began Benchmark Period processing in FY 1995. The AVHRR Level 1B GAC data that serves as the processing input (including new calibration tables designed to stabilize the calibration and provide inter-instrument calibration) are also a Pathfinder product. Transcription teams at NASA and NOAA copied more than 30,000 magnetic tapes to almost 400 optical disks, each holding 6 GB of data. This effort was completed at the end of 1992.

The GOES Pathfinder activity first supported a study concerning the quality of existing GOES data, with a report supplied to the GOES Pathfinder SWG. To carry out subsequent SWG recommendations on GOES Pathfinder processing, an intensive development effort at the University of Wisconsin's Space Science and Engineering Center (SSEC) created a product generation system able to ingest data at 3.6 times the available real-time capability. This development was key because of the large GOES archive, over 115 TB of data dating back to 1978. Initial GOES Pathfinder product generation began in the spring of 1993, with Benchmark Period complete in March 1994.

A TOVS Implementation Team meeting was held in June 1992. A set of geophysical parameters for specific spatial/temporal scales was selected for inclusion into the NOAA-10 Benchmark Period data set. TOVS Pathfinder data sets are being created using three distinct processing methodologies: Path A at GSFC, Path B at the Laboratoire de Meteorologie Dynamique/Atmospheric Radiation

Analysis Group (LMD/ARA) at École Polytéchnique in Paris, France, and Path C at both NOAA/NESDIS and Marshall Space Flight Center (MSFC). Path A uses an interactive physical retrieval algorithm, while Path B uses a classification technique to provide atmospheric retrievals of a suite of parameters. In addition, a Path P has been added using the Path B methodology in order to focus on the problematic Arctic polar region. The Path C approach is to provide products for deeper atmospheric layers, using little or no *a priori* information. TOVS Pathfinder data continue to be processed by the five teams, which also coordinate intercomparison and validation of the results. The GSFC, MSFC, and National Snow and Ice Data Center (NSIDC) DAACs, and NOAA will archive and distribute final products.

The SSM/I Pathfinder is creating a suite of products at both Levels 2 and 3. The Level 1 antenna temperatures will be converted to Hierarchical Data Format (HDF), and the swath products are being generated at MSFC; the Level 3 gridded products are being generated at NSIDC. The Benchmark Period data sets are all complete as of the end of CY 1994. Archiving of the product suites varies by discipline interest in specific products. A CD-ROM containing selected products has been planned for early distribution.

The NASA SMMR Pathfinder team at JPL has retrieved the SMMR data from a large number of low-density magnetic tapes and reprocessed the data to a Level 1B data set. The original SMRR flight was experimental, and the archived SMMR data exhibited a number of calibrational anomalies. A science review team was formed, and met to review the proposed reprocessing effort before it was begun.

These data sets have now been fully processed and documented, and were provided to the MSFC DAAC in early 1995 for archiving and distribution.

The goal of the Landsat Land Cover Pathfinder effort is to establish long-term, medium-to high-resolution data sets for particular regional and global applications to global change research. The Landsat Pathfinder SWG has defined several projects to address land cover change. Within the Tropical Deforestation Project, NASA and EPA are funding selected universities to produce a three-epoch forest/no-forest data set showing areas of deforestation, derived from each of the moist tropical forested regions, i.e., the Amazon, Central Africa, and Southeast Asia. EPA has taken the lead in a second project to produce three epochs of wall-to-wall MSS coverage of coterminous North America.

In 1994, NASA also began a third Landsat Pathfinder project, called the Global Land Cover Test Sites Project. This project is developing a multi-temporal satellite data base for selected test sites to support the research on land cover characterization and the testing and validation of improved satellite algorithms for EOS. These sites have been chosen because of well-established or emerging long-term field monitoring and *in situ* field expertise and infrastructure to provide high-resolution data representing different environmental conditions. The Pathfinder Program expects to create additional data sets related to global change monitoring issues in such areas as biology, ecology, geology, hydrology, atmospheric sciences, and social sciences.

A Pathfinder Interuse Workshop was held in July 1992, to determine standards and to identify solutions to problems associated with formats, projections, resolution, and binning; the objective was to facilitate Pathfinder data product integration. The workshop resulted in the resolve to use, when possible, the EOSDIS Version 0 prototype standard, HDF, as the common data format. A smaller technical group is being formed to work intensively on the remaining problems of binning, resolution, and projection, with results expected in 1-to-2 years. Technology continues to improve the capability to interuse and fuse data sets. However, compatible choices of standards such as data models and temporal and spatial resolutions “up front” where possible does simplify user data management.

A NASA Pathfinder Research Announcement was issued in December 1994 in order to continue, rationalize, and strengthen NASA’s MTPE support of data product generation activities. Proposals received in March 1995 were evaluated through a scientific and technical peer review, and also were reviewed for scientific and programmatic relevance to the research interests of NASA’s MTPE and the USGCRP. The continuation of this program reflects the NASA view that data quality and availability are key to successful Earth system science.

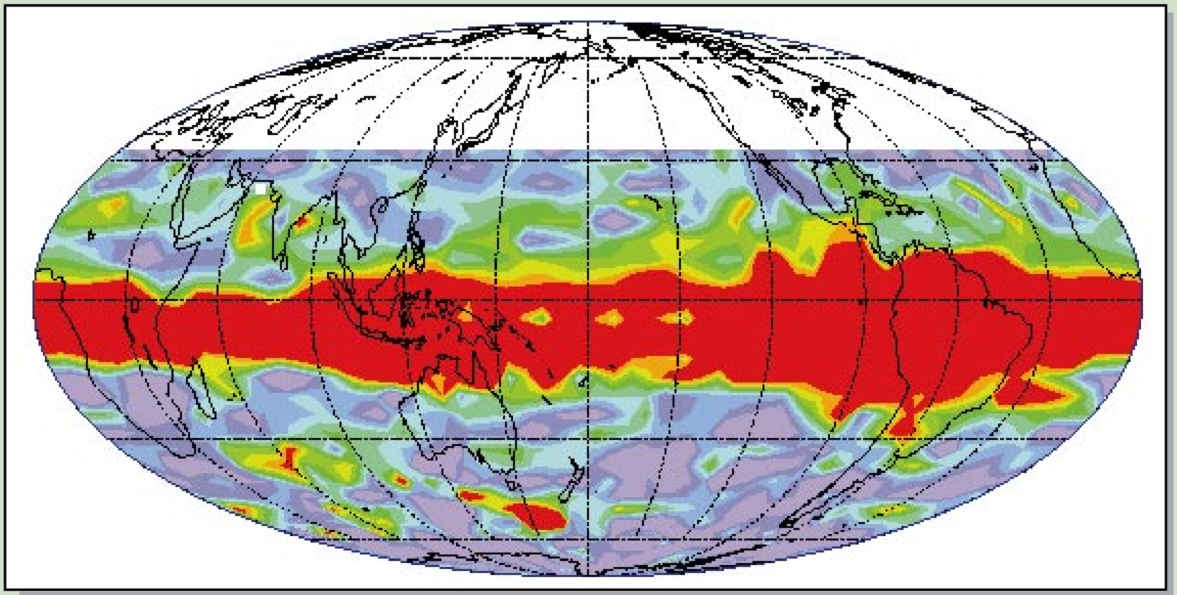
NOAA-NASA, 1994: *The NOAA-NASA Pathfinder Program (August 1994).* Published by the University Corporation for Atmospheric Research (NOAA Award No. NA27GPO232-01), 23 pp.

Special Issue, 1994: Global data sets for the land from the AVHRR. *Int. J. of Remote Sensing*, **15**, (17), 3315-3639.

Pathfinder WWW Home Page URL:

http://xtreme.gsfc.nasa.gov/hq/path_sites.html

MLS and Mount Pinatubo



Mount Pinatubo, after being dormant for more than 600 years, erupted several times in June 1991 with the major event occurring on June 15, spewing approximately 20 million tons of sulfur dioxide (SO_2) into the atmosphere. By mid-July the SO_2 cloud had traveled around the entire globe. On September 21 worldwide levels of SO_2 were measured by the Microwave Limb Sounder (MLS) on the Upper Atmosphere Research Satellite (UARS) and are depicted in this figure. The SO_2 gas reacts with water in the stratosphere to form sulfuric acid aerosol particles. These particles increase the amount of sunlight reflected back to space, thus having a cooling effect on the Earth's climate. The relative cooling caused by the Mount Pinatubo eruption helped to make 1992 the coolest year since 1986. Also, the resultant aerosols from the Mount Pinatubo eruption are believed to have contributed to reduced ozone concentrations over the polar region of the Southern Hemisphere.

The colors ranging from light green to bold orange indicate the increase in sulfur dioxide that followed the eruption of Mount Pinatubo.

An MLS instrument is part of the instrument payload of the EOS CHEM-1 mission planned for launch in 2002.

EOS Data Quality: Calibration,Validation, and Quality Assurance

EOS Data Quality: Calibration, Validation, and Quality Assurance

Data quality for EOS is ensured through activities in three areas: calibration, validation, and quality assurance. The primary objective of EOS calibration and validation activities is to characterize and document the accuracy and precision of EOS observations and derived biophysical and geophysical products over all relevant temporal and spatial scales. More specifically these two activities are: 1) radiometric calibration and characterization of EOS instruments; and 2) validation of the observations and state variables, fluxes, and parameters derived either directly from EOS observations or in conjunction with the data assimilation method(s) and integrated Earth system models. The purpose of quality assurance (QA) is to identify and flag highly corrupted data, typically caused by processing errors. All of these activities will be coordinated by the Panel on Data Quality (PDQ) of the EOS Investigators Working Group. The PDQ is supported by the Calibration and Validation Scientists residing within the EOS Project Science Office.

Radiometric Calibration

The objective of this activity is to characterize and document measurement accuracy and precision of the EOS instruments. There are three types of radiometric calibration activities currently planned for the EOS Program: 1) laboratory calibration prior to launch, 2) inflight calibration with onboard calibrators, and 3) vicarious calibration during the post-launch period. The laboratory calibration activities will focus on calibration of individual instruments with traceability to radiometric standards accepted by the national and international metrology community and implemented by organizations such as the National Institute of Standards and Technology (NIST) in the U.S. This step also includes the intercalibration of instruments that operate based on the same physical principles, in the same region of the electromagnetic spectrum, and measure similar characteristics of the Earth system. For example, transfer radiometers will be used in round-robin intercomparisons that will enable the transfer of metrology scales, maintained at national standards laboratories, to surface-imaging instruments such as ASTER, MODIS, and MISR that will be launched on the EOS AM-1 satellite. The inflight calibration will utilize calibration lamps, reference surfaces with known reflectivity/emissivity, deep space, and ratioing radiometers. The vicarious methods include the use of bright and dark targets on Earth, coincident sub-orbital flights of standard spectroradiometers over well-characterized Earth surfaces, and use of the Moon as an especially stable reference target that will be characterized from high spectral and spatial resolution measurements made from ground-based observatories over the libration cycle of the Moon.

EOS Validation Strategy

The purpose of the validation activities is to obtain the information necessary to determine the uncertainties associated with EOS geophysical data products. These products are derived either directly from EOS observations or in conjunction with data assimilation and Earth system models. Achievement of this goal requires information related to the accuracy of the instrument product and the knowledge of the scales and conditions of interest to the users of the product.

These activities are carried out at several different levels. The EOS instrument science teams are responsible for validation of the algorithms and data products they produce. Thus, members of the instrument science teams identify the necessary steps required to validate their respective data products on specific space and time scales. Intercomparison of similar data products developed by different instruments based on different techniques is coordinated by the respective instrument science teams. For example, cross comparison and validation of cloud products developed by CERES, MISR, and MODIS instruments requires close coordination among the responsible members of the science teams for these instruments. The end users of these products, e.g., interdisciplinary investigators, participate in validation activities to ensure that uncertainties and associated statistics provided for each product meet their requirements. In addition, the interdisciplinary and four-dimensional data assimilation teams also plan on validating their model results, based on remotely sensed and *in situ* observations. Each Level-1 through Level-3 product will have an associated uncertainty estimate; this is expected to include both a basic error estimate for that product (long-term radiometric, spectral and spatial resolution and accuracy) and time-based indications of larger uncertainties that result from unusual conditions.

To obtain the necessary *in situ* observations required for validation, the EOS Program will rely on several activities: 1) surface-based observations obtained by the EOS interdisciplinary and instrument investigations; 2) participation in, and support of, national and international coordinated field experiments such as LAMBADA-BATERISTA and GEWEX, planned under the auspices of WCRP and IGBP; and 3) coordination with national and international field programs such as the Department of Energy (DoE) Atmospheric Radiation Measurement (ARM) Program, the National Science Foundation (NSF) Long-Term Ecological Research (LTER) sites, and the WCRP Baseline Surface Radiation Network (BSRN).

Quality Assurance

The objective of quality assurance (QA) is to identify and flag data products, at the granule level, which clearly do not conform to the expected accuracy for the particular product. Automatic identification algorithms will be provided to detect data that fall outside of specified allowed ranges.

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Education Programs

Education Programs

While the goal of Mission to Planet Earth is increased scientific understanding, the ultimate product of the program is education, in its broadest form. One of the four goals of the program, as cited in the Mission to Planet Earth Strategic Plan, is to "foster the development of an informed and environmentally aware public." Within this context, contributions by Mission to Planet Earth to the advancement of public knowledge about the Earth are key to measuring the success of the program.

NASA's Education Framework

All formal NASA education activities are part of the NASA Education Framework. This framework includes three components: program content, education levels, and implementation approaches. Program content reflects the science and engineering efforts underway within NASA and the enabling capabilities that support them. Education levels are divided between kindergarten through fourth grade, fifth through eighth grade, ninth through twelfth grade, and undergraduate, community college, and graduate levels. The implementation approach defines the purpose of the activity. The following categories represent the various implementation approaches used in NASA:

- **Teacher preparation and enhancement**—Programs are designed to enhance teacher/faculty knowledge and research skills through exposure to the NASA mission, facilities, and resources for use in the teaching enterprise.

- **Curriculum support**—Create, utilize, and disseminate instructional products based on NASA's unique mission and resources in the areas of science, mathematics, and technology.

- **Student support**—Student support provides research experiences for students at NASA and related sites, provides experiences and exposure to NASA's mission, including science, mathematics, engineering, and technology, and provides support to train students in the areas of science, mathematics, and engineering.

- **Educational technologies**—Programs and products that develop and use advanced technologies for education including, but not limited to: Internet services, CD-ROM databases, live or taped video, computer software, multimedia systems, virtual reality, educational technology research and development, databases, and dissemination systems.

- **Systemic change**—Systemic activities typically involve collaborative efforts with a range of partners, seeking to enhance multiple aspects of the educational process.

Mission to Planet Earth Education Strategy

In support of the NASA education initiative, the Office of MTPE is working with the Education Division to establish a focused, sustainable education strategy. The strategy includes all education programs and activities at all MTPE field centers and NASA Headquarters. Principles, objectives, priority elements, and an implementation plan are part of the overall strategy to insure that MTPE has a solid education program with the ability to grow.

Overriding principles have been established to consider when working to meet specific MTPE Education objectives:

- Education, in the broadest sense, is the ultimate product of MTPE.

- We must, through our efforts, demonstrate relevance to society.

- We must operate and work within NASA's strategy for education.

- We must focus implementation of a sustainable Earth system science education program that is consistent with externally imposed education standards.

- Scientists must continue and increase their involvement in education.

- Teachers must be involved in the development and decision-making aspects of education activities.

- NASA strategy and programs must be coordinated (and perhaps integrated) with other agencies/organizations.

- Attention to equity and diversity must be a component in all MTPE education activities.

- NASA provides the first level of translation for science information, and, when appropriate, leverages resources of external groups for further translation.

These guiding principles define our approach to achieve the following objectives:

- Train next generation of scientists to use an interdisciplinary, Earth system science approach.

- Continue to educate and train educators as research evolves and capabilities change.

- Raise awareness of policy makers and citizens to enable prudent policy determination regarding global change.

- Improve science and math literacy.

- Improve interface between educators and scientists and secure greater support by scientists for broad education efforts.

- Explore mechanisms to leverage the development of materials and products, where reasonable, to:

    a) increase resources availability,

    b) increase knowledge base, and

    c) encourage the development of an external capability, expert in translating scientific research into usable forms for a continuum of customers.

Prioritization of educational activities is not a clear-cut procedure. In order to meet the objectives above, a complement of activities, using the various implementation approaches must be performed. However, there are certain priority elements to consider when implementing a focused, sustainable program. We must maintain support for graduate students and the establishment of curricula in universities that pursue an interdisciplinary Earth system science concept, in the hope of establishing an educated community in the near term to analyze data from the EOS missions and provide accurate information on global change to policy makers. MTPE must also educate present and future educators if its efforts are to reach a national, diverse population of students. A further priority will be continued encouragement to use technology in pre-college activities as technology allows for increased hands-on, interactive learning.

In order to prioritize education activities in MTPE in concert with the strategy objectives, a peer review process has been established to involve scientists and educators in the review of all proposals for educational activities submitted to MTPE. In the future, based on the knowledge gained from the strategy process of FY 95, MTPE plans to incorporate educational requirements in relevant research announcements and separately solicit experts to fill in the gaps of the strategy to meet the needs of educators and the obligations of this agency.

Global Change Fellowship Program

A primary student support activity at the higher education level is the Graduate Student Fellowship in Global Change Research. The EOS science budget contains a special fund for education in Earth system science. The Graduate Student Program in Global Change Research was established in 1990 to support graduate students pursuing a Ph.D. degree in Earth system science. Fellowships are awarded for an initial 1-year term and may be renewed annually for up to 2 more years, based on satisfactory progress as reflected in academic performance and evaluations made by faculty advisors. The amount of the award is $20,000, which may be used as a stipend to defray living expenses, tuition, travel, books, supplies, and fees. An additional $2,000 is available by request for the faculty advisor's use in support of the student's research. More than 300 fellowships have been awarded during the first 4 years of this program. It is envisioned that NASA will support about 150 fellows each year for the duration of the program, thereby ensuring a pool of highly qualified Earth scientists to disseminate the data generated during the 15-year mission lifetime.

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

Petitions for a Graduate Student Fellowship in Global Change Research entail a completed application form, copies of undergraduate and graduate transcripts (if applicable), a letter of reference from the academic advisor, and a titled five-page research proposal for those already enrolled in a program of study or a statement of research interest for those just entering graduate school. Instructions for preparing the research proposal and the ancillary forms can be acquired by sending written queries to:

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

Global Change Fellowship information packets are available each January, and must be completed by March 15 to be considered for the following academic year. Ten copies of the application form, proposal, transcripts, and letter of reference need to be forwarded as a package to the above address. Incomplete packages and/or those received after the March 15 deadline are not considered in the selection process.

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

Competition for a Graduate Student Fellowship in Global Change Research is quite fierce. Over 1,700 applications have been submitted since program inception in 1990. To date, more than 300 fellowships have been awarded, with the chosen students representing 61 universities and 19 countries. Refer to Tables 10a through 10e for a listing of the current fellowship recipients. U.S. citizens and resident aliens are given preference in the review process; however, this does not preclude foreign nationals who are pursuing their graduate studies in the U.S. from applying.

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

Table 10a. **Global Change Fellowship Recipients - 1993-1994**

GCC	Fellow	Citizenship	Institution	Proposal Title
Biogeochemical Dynamics	Ball, Christopher	USA	Ohio State University	Retrieval Parameters for Atmospheric Remote Sensing: Experiment and Theory
	Barnes, Diana	USA	Harvard University	Sources and Sinks of Greenhouse Gases in Forest Ecosystems: A Novel Application of Conditional Sampling
	Clayton, Tonya	USA	University of South Florida	Biophysical Interactions in the Surface Layer of the Equatorial Pacific Ocean
	Foley, David	USA	University of Southern California	A Model of Coupled Biological and Physical Processes in the Equatorial Pacific During the 1991-1992 ENSO Event
	Goldfarb, Leah	USA	University of Colorado Boulder	Photodissociation of Atmospheric Chlorine Species: ClOOCl and $ClONO_2$
	Heilman, Mark	USA	University of Notre Dame	Methane Cycling and Release from Littoral Sediments: Effects of Submersed Vascular Plants
	Hughes, Richard	USA	Oregon State University	Biomass and Nutrient Dynamics in Perturbed Ecosystems of Rondonia Brazil
	Johansson, Annika	Canada	Columbia University	The Global Miocene Silica Event in Grasses and Diatoms: Causes and Correlations
	LaCapra, Veronique	USA	University of California Santa Barbara	Land Use Change in a Seasonally Flooded System: The Biogeochemical Implications of Biomass Burning in Tropical Wetlands
	Mather, James Howard	USA	Pennsylvania State University	Measurement of Tropospheric OH Using a Laser-Induced Fluorescence Technique
	McKenzie, Lisa Marie	USA	University of Montana	Emission of Halocarbons from Biomass Burning
	McSwiney, Claire	USA	University of New Hampshire	Control of NO_x Loss Across a Tropical Rain Forest Ecosystem in the Luquillo Forest, P.R. under Baseflow and Storm Conditions
	Megonigal, James	USA	Duke University	Feedbacks of CO_2-Fertilization and Temperature on Methane Emissions
	Peterson, Matthew	USA	Michigan Technological University	Extended Time-Series Observations of NO & NO_y from the Azores
	Shippert, Margaret	USA	University of Colorado Boulder	A Model of Methane Flux From Arctic Tundra Using Remotely Sensed Data
	Smith, Nathalie	USA	University of Colorado Boulder	High-Resolution Records of the Atlantic Intertropical Convergence Zone Derived from Coral Isotopic Measurements
	Sobel, Adam	USA	Massachusetts Institute of Technology	A Proposal to Study the Three-Dimensional Transport of Trace Gases in the Stratosphere

Table 10b. Global Change Fellowship Recipients - 1993-1994

GCC	Fellow	Citizenship	Institution	Proposal Title
Climate & Hydrologic Systems	Adkins, Jess	USA	Massachusetts Institute of Technology	Linking Surface Climate Change to the Deep Ocean: The Use of Deep Sea Coral and Satellite Data
	Albertson, John	USA	University of California Davis	Investigating Land-Atmosphere Interaction Over Heterogeneous Surface Using Large Eddy Simulation With Remotely Sensed Data
	Bennet, Andrew	USA	Massachusetts Institute of Technology	Verification and Enhancement of Satellite Observation Data Using Automomous Underwater Vehicles
	Bergman, John William	USA	University of Colorado Boulder	The Diurnal Cycle of Atmospheric Water Vapor and Clouds and Its Impact on Regional and Global Energy Budgets
	Byrne, Deirdre	USA	Columbia University	Agulhas Eddies: Assessing the Impact of Mesoscale Variability on Ocean Circulation
	Chung, Chul	Korea	University of Maryland College Park	Asian Monsoon - El Niño Interaction: Impact on Global Climate Change
	Ciach, Grzegorz Jan	Poland	University of Iowa	Satistical and Physical Framework for Design and Verification of Climatological Precipitation Estimation Methods Using Remote Sensing Measurements
	Cox, Helen	UK	University of California Los Angeles	Analysis of Stratospheric Aerosol Data from SAGE II: Chemical and Microphysical Modeling
	Dana, Gayle	USA	University of Nevada Reno	Monitoring Glacial Meltwater Generation in the McMurdo Dry Valleys LTER Site Using Satellite Data
	Dawson, Michael	USA	University of Texas Arlington	Development of an Advanced Information Retrieval Technique From Remotely Sensed Multispectral Data
	Early, David	USA	Brigham Young University	Remote Satellite Observation of Polar Ice and Snow Cover
	Erxleben, Wayne	USA	University of Arizona	Assessment, Characterization and Modeling of Aerosol Temporal-Spatial Properties for Use in Global Climate Change Studies
	Evans, Michael	USA	Columbia University	Natural Variability, Evolution, and Response of the Southern Oscillation to Global Climate Change
	Frei, Allan	USA	Rutgers University	Anthropogenic Global Climate Change Detection Using Remotely-Sensed Northern Hemisphere Snow Cover Data
	Friedman, Michael	USA	University of Wisconsin Madison	A Complete Vertical Radiative Energy Budget Over the Ocean: Applications to TOGA-COARE
	Gupta, Mohan Lal	India	University of California Irvine	A 2-Dimensional Photochemical Study of Light Nonmethane Hydrocarbons in the Troposphere
	Haferman, Jeffrey	USA	University of Iowa	Three-Dimensional Radiative Transfer in Cloudy Precipitating Atmospheres
	Haverkamp, Donna	USA	University of Kansas	A Methodology for Classifying Remotely Sensed Sea Ice Cover for Global Change Applications
	Hollenbeck, Karl	Germany	University of Virginia	Improved Regional-Scale Effective Parameterization of Land Surface Hydrological Dynamics Through Inverse Estimation and Microwave Remote Sensing
	Horowitz, Larry	USA	Harvard University	Effect of Anthropogenic Emissions from North America on the Global Tropospheric Budget of NOY
	Jipp, Peter	USA	Duke University	Evapotranspiration in Seasonally Dry Amazonian Ecosystems: Water Budget Responses to Forest Removal and Regrowth
	Karner, Daniel	USA	University of California Berkeley	Testing the Milankovitch Theory of Climate Cycles by Single Crystal 40Ar/39Ar Dating of Coastal Pleistocene Volcanics
	Knabb, Richard	USA	Florida State University	Monitoring Aspects of Water Vapor Structure and Transport Which Influence Climate Variability Using the New Capabilities of GOES I
	Kohfeld, Karen	USA	Columbia University	North Atlantic Surface Ocean Response to Younger Dryas Cooling as Recorded in Planktonic Foraminifera, and Its Implications for Rapid Climate Change
	Lin, Xin	China	Colorado State University	Invest. of Heating and Moistening Evolution Over Western Pacific Warm Pool Region and Its Relation to the 30-60 Day Oscillation

Table 10c. Global Change Fellowship Recipients - 1993-1994

GCC	Fellow	Citizenship	Institution	Proposal Title
Climate & Hydrologic Systems	Lipscomb, William	USA	Unviersity of Washington	The Response of Sea Ice to Greenhouse Warming
	Masina, Simona	Italy	Princeton University	Spatial and Temporal Variability of Instability Waves in the Tropical Pacific Ocean
	Masters, Jeffrey	USA	University of Michigan	Vertical Transport of Boundary Layer Trace Gases by Mid-Latitude Cyclones
	Mauget , Steven	USA	University of California Davis	Divergent Influence and Intraseasonal Teleconnections: An Observational Study Using ISCCP Cloud Cover Data
	Mauzerall, Denise	USA	Harvard University	The Influence of Fossil Fuel and Biomass Combustion on Ozone Concentrations in the Remote Troposphere
	McCollum , Jeffrey	USA	University of Iowa	Rainfall as a Space-Time Process and Its Climatology Estimated from Space
	McConnell, Joseph	USA	University of Arizona	Investigation of the Transfer Function Between Snow and Atmosphere Concentrations for Reversibly Deposited Chemical Species
	McManus, Jerry	USA	Columbia University	North Atlantic Ice Rafting Events and Rapid Climate Change
	Myrick, Jennifer	USA	University of Colorado Boulder	Analysis of Errors Affecting Satellite Altimeter Data for Global Change Applications
	Oertling, Annette	USA	Tulane University	Small Scale Processes in Sea Ice Modeling
	Orris, Rebecca	USA	Princeton University	A Test of the Consistency of the Modeled and Observed Middle Atmosphere Temperature and Ozone
	Oxburgh, Rachel	Britian	Columbia University	Variations in the Isotopic Composition of Osmium in Seawater Over Time
	Parada, Robert	USA	University of Arizona	In-Flight Radiometric Calibration Methods for Satellite Sensors Over Dark Targets
	Pazdalski, Jeffrey	USA	Oregon State University	Investigations of Directly Wind Forced Mesoscale Oceanic Variability Using Remotely Sensed Data
	Perica, Sanja	Crotia	University of Minnesota	Physically-Based Subgrid Scale Statistical Parameterization of Rainfall: Coupling Mesoscale Meteorology with Small Scale Scaling Descriptions
	Petersen, Walter	USA	Colorado State University	Electrified Tropical Convection: Implications for Use of the TRMM Lightning Imaging Sensor in Tropical Rainfall and Heating Calculations
	Pierson, James	USA	University of California Irvine	Mechanistic and Experimental Studies of Halogen Oxide Species Important in the Lower Stratosphere
	Pinto, James	USA	University of Colorado Boulder	Autumnal Expansion of Sea Ice in the Beaufort Sea
	Reising, Steven	USA	Stanford University	Thunderstorm Associated Rainfall Over the Pacific Ocean Inferred from Long Range Sferics Measurements
	Sanyal, Abhijit	India	Columbia University	Estimation of Paleo-pH of Oceans Based on Boron Isotopic Composition of Foraminifera
	Sayler, Bentley	USA	University of Washington	Study of Cloud Mixing Processes and Dynamics Through Laboratory Simulations
	Shaw, Raymond	USA	Pennsylvania State University	A Proposal to Study the Microphysics of Cirriform Clouds
	Soman , Vishwas	USA	Texas A&M University	Numerical Estimation of Sampling Errors For A Space-Borne Sensor Using Darwin Rainfall Data
	Stevens, Bjorn	USA	Colorado State University	Use of the Large Eddy Simulation Technique to Explicity Model the Microphysics of Marine Stratocumulus
	Thornton, Peter	USA	University of Montana	Dev. and Testing of a Two-Way Coupling Between Land Ecosystem and Mesoscale Atmospheric Dynamic Models on a Reg. Scale
	Voemel, Holger	Germany	University of Colorado Boulder	Measurements of Stratospheric Water Vapor in the Tropics and Over Antarctica

Table 10d. **Global Change Fellowship Recipients - 1993-1994**

GCC	Fellow	Citizenship	Institution	Proposal Title
Data and Info. Sys.	Bogdanovich, Predrag	USA	University of Maryland College Park	A TREE: Data Structure to Support Very Large Scientific Databases in Global Change Research
	Cloud, John	China	University of California Santa Barbara	Exploring the Potential of Space Shuttle Earth Observations Photography as Metadata to Access and Manage Earth System Data
	Goldschneider, Jill	USA	University of Washington	Lossy Compression of Multi Spectral Digital Satellite Images
	Korkuchansky, Alex	Ukraine	Northwestern University	Load Balancing And Caching In Disk Arrays
Ecological Systems and Dynamics	Adams, Phyllis	USA	Duke University	Effects of Global Climate Change on the Landscape Pattern of the Tanana River Floodplain in Interior Alaska
	Alward, Richard	USA	Colorado State University	Alterations in Species Composition of Grassland Communities Resulting from Climate Change: Will Increased Temperatures Change the Nature of Plant-Herbivore Interactions
	Anyamba, Asaph	Kenya	Clark University	Time Series Analysis of Vegetation Response to Climatic Variations Using Satellite Derived Normalized Difference Vegetation Index Data: Observations Over Africa During the 1981-1991 Period
	Austin, Amy	USA	Stanford University	The Differential Effects of Water in Ecosystem Function
	Berwald, Juli	USA	University of Southern California	Bio-optical Analysis of Oceanic Remotely Sensed Reflectance
	Caspersen, John	USA	University of Connecticut	Forest Community Responses to Changes in Water Availability
	Courteau, Jacqueline	USA	University of Michigan	Genotypic Differences In Aspen Response To Elevated CO_2
	Duncan, Jeff	USA	San Diego State University	Testing High Spectral Res. Models for Minitoring Surface Cover Param in the Sahel for Use in Global Change
	Edwards, Joanne	USA	Florida State University	Resolving a Major Discrepancy Regarding the Importance of Rhizospheric Methane Oxidation
	Hurtt, George	USA	Princeton University	Ocean Ecosystem Models for Use in Studies of the Oceanic Uptake of Atmospheric CO_2
	Kneller, Margaret	USA	Columbia University	Vegetation and Climate Records from the U.S. Southeast: Glacial to Holocene Changes
	Kupferberg, Sarah	USA	University of California Berkeley	Climate Change and the Invasibility of River Communities
	Mack, Michelle	USA	University of California Berkeley	Ecosystem Consequences of Changes in Biodiversity
	McFadden, Joseph	USA	University of California Berkeley	Growth Form-Mediated Controls on Water and Energy Balance in Arctic Tundra
	Navarro, Ana Josefina	USA	University of Puerto Rico	Comparative Abundance and Pigment Physiology of Trichodesmium Community in the Caribbean Sea Near Puerto Rico
	Newman-Osher, Laurie	USA	University of California Berkeley	Sequestration and Turnover of Soil Organic Carbon: The Roles of Land Use Change and Mineralogy
	Randerson, James	USA	Stanford University	Exploring Atmosphere - Terrestrial biosphere CO_2 Fluxes Using a Bioshpere Model driven by satellite data
	Sachs, Donald	USA	Oregon State University	The Effect of Forest Management on Carbon Storage by Engelmann- Spruce - Subalpine Fir Forests in British Columbia
	Saleska, Scott	USA	University of California Berkeley	Global Warming and Ecosystem Carbon Storage: An Experimental Investigation of Ecologically-Mediated Climate Feedbacks from a Terrestrial Ecosystem
	Shaw, Mary	USA	University of California Berkeley	Ecosystem and Population Consequences of Climate Change in a Montane Meadow
	Suzuki , Marcelino	Brazil	Oregon State University	The Effect of Protistan Bacterivory in Bacterioplankton Diversity
	Voss, Paul	USA	Harvard University	Heterogeneity of Carbon Dioxide in Forest Ecosystems
	Yang, Jingli	China	University of Maryland College Park	African Savanna Vegetation Changes Using Historical Landsat Archive

Table 10e. **Global Change Fellowship Recipients - 1993-1994**

GCC	Fellow	Citizenship	Institution	Proposal Title
Human Interactions	Brondizio, Eduardo	Brazil	Indiana University	Land-Use Change in the Amazon Estuary: Agriculture, Secondary Succession, and Agroforestry of Native Populations
	Horne, L Christine	USA	University of Arizona	Micro-Level Social Determinants of the Greenhouse Effect
	Lehman, Paul	USA	University of Texas Austin	Human Interaction with the Earth's Environment in Long-Term Perspective
	Litvak, Marcy	USA	University of Colorado Boulder	The Effects of Resource Availability and Herbivory on Monoterpene Emissions from Conifers
	Steininger, Marc	USA	University of Maryland College Park	Monitoring the Fates of Cleared Land in Amazonia
	Walker, Wendy	USA	Johns Hopkins University	Conserving Madagascar: A Comparative Study of Local and International Approaches
	Wilson, Frederick	Sierra Leone	Jackson State University	Use of Geographic Information Systems (GIS) and Remote Sensing (RS) to Study the Effects of Human Activities (Landuse) on Climate Change Along the Mississippi Gulf Coast
Solar Influences	Cordero, Eugene	USA	University of California Davis	Solar Influences on the Dynamics of the Equatorial Middle Atmosphere
	Goss, Lisa Mae	USA	University of Colorado Boulder	Time-Resolved Fourier Transform Spectroscopy of Ozone Photo-Fragments
Solid Earth Process	Childers, Vicki	USA	Columbia University	Precise GPS Positioning to Study the Geologic Influences on the Stability of the West Antarctic Ice Sheet
	Heine, Jan	Germany	University of Washington	Climatic Change in the Western United States at the Last Glacial/Interglacial Transition - A Glacial Chronology On and Near Mt. Rainier Volcano, Washington
	Hsieh, Jean	Canada	California Institute of Technology	Calibration and Use of the Oxygen Isotope Paleoclimatic Signal Locked in Pedogenic Clay Minerals
	Nicoll, Kathleen	USA	University of Arizona	Sedimentary Evidence for Climate Change in the Western Desert, Egypt
	Putnam, Scott	USA	University of Utah	Linking Lithospheric, Atmospheric and Biosphere Signals of Climate Change: A Test Along a North American Transect
	Schneider, David Joseph	USA	Michigan Technological University	Satellite Observations of Explosive Volcanic Eruptions: The Fate of Silicate Particles in the Atmosphere
	Wills, Joanna	USA	Harvard University	Volcanostratigraphic Intercorrelation of Paleoclimate Proxy Records and Dating of the Terminations II-III Via High Precision 87 Rb- 87 Sr Chronometry
	Yuhas, Roberta Hope	USA	University of Colorado Boulder	Landscape Response to Holocene Climate Change: Evidence from Remotely Sensed Data and Ground-Based Studies in Northeastern Colorado

International Cooperation

International Cooperation

The Earth Observations International Coordination Working Group (EO-ICWG) is the forum within which the U.S., Europe, Japan, and Canada discuss, plan, and negotiate the international cooperation essential for implementation of the International Earth Observing System (IEOS) in the 1990s and beyond. The delegations to EO-ICWG are led by the Earth observations offices of their respective space agencies: The National Aeronautics and Space Administration (NASA); the European Space Agency (ESA); the Japanese Science and Technology Agency (STA); and the Canadian Space Agency (CSA). The delegations also include respective operational environmental monitoring and Earth observation agencies: The United States National Oceanic and Atmospheric Administration (NOAA); the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT); the National Space Development Agency (NASDA) of Japan, the Japanese Ministry of International Trade and Industry (MITI), the Japan Meteorological Agency (JMA), and the Japan Environment Agency; and the Canadian Atmospheric Environment Service (AES). The EO-ICWG meets two to three times per year, addressing a full range of technical and policy issues, which include payload, operations, data management, data policy, and instrument interfaces. EO-ICWG has defined the elements listed below as the space-based component of IEOS:

- NASA's Earth Observing System (EOS), beginning with AM-1;
- Japanese Earth Observing System (JEOS), beginning with the Advanced Earth Observing System (ADEOS);
- NASA/Japanese Tropical Rainfall Measuring Mission (TRMM) and its follow-ons;
- the European ENVISAT and METOP missions; and
- NOAA's Polar-Orbiting Operational Environmental Satellite (POES) series, beginning with NOAA-N.

Tables 11a through 11c (provided by EO-ICWG) list the IEOS satellites and their respective instrument complements.

Given the transience of national budget scenarios (and consequently scheduling), these charts should be considered planning documents. Refer to the *Mission Elements* section of this Handbook for more detail on the various spacecraft and sensors that constitute the space-based elements of IEOS.

The following paragraphs offer brief synopses of the partner nation contributions.

Europe

European Earth observing satellites include ENVISAT-1 for environmental monitoring and atmospheric chemistry and the METOP series (METOP-1/2/3) for operational meteorology and climate monitoring. The spacecraft, instrumentation, launch, operations, and associated data system are provided through ESA, individual member state contributions, EUMETSAT, and contributions from NOAA for the operational payload on METOP. ESA's plans call for launch of ENVISAT-1 in

Table 11a. **The International Earth Observing System**

PROPOSED INSTRUMENT CONFIGURATION 1996 - 1998

OBJECTIVES	Radarsat 3Q 1995	NOAA-K 833 km 7:30 AM 2Q 1996	ADEOS 797 km 10:30 AM 3Q 1996	TRMM 350 km 35° Incl. 3Q 1997	NOAA-L 870 km 1:40 PM 4Q 1997	EOS AM-1 705 km 10:30 AM 2Q 1998	FOO/Color 705 km Noon 1998	Meteor 3M-1 Polar 9:15 AM 3Q 1998	ENVISAT-1 790 km 10:00 AM 4Q 1998	Landsat-7 705 km 10:00 AM 4Q 1998
Status	APPROVED									
VIS/IR Imagers		AVHRR/3	OCTS, AVNIR, POLDER	VIRS, LIS	AVHRR/3	MODIS, ASTER, MISR	Ocean Color Instrument		AATSR, MERIS	ETM+
Radiation Budget				CERES (1)		CERES (2)			ScaRaB	
Passive Atmospheric Sounding		AMSU-A 1/2 AMSU B HIRS/3			AMSU-A 1/2 AMSU B HIRS/3					
Passive Microwave				TMI						
Active Microwave			NSCAT	PR					ASAR	
Tropospheric Chemistry			IMG			MOPITT			SCIAMACHY	
Stratospheric Chemistry		SBUV/2	TOMS, ILAS		SBUV/2			SAGE III	GOMOS, MIPAS, SCIAMACHY	
Radar Altimeter									RA-2	
Laser Altimeter										
Other	C-Band SAR	SEM ARGOS S&R	RIS		SEM ARGOS S&R				PRAREE	
Operational Instruments		All Sensors			All Sensors					
Tropospheric Wind Lidar		*Solid-state laser technology development is under way in support of this objective*								

Table 11b. **The International Earth Observing System (cont'd)**

PROPOSED INSTRUMENT CONFIGURATION 1999-2001

OBJECTIVES	EOS Radar ALT TBD 1999	EOS ACRIMSAT 98° Incl. 1999	ADEOS-II 800 km Polar 1Q 1999	NOAA-M 833 km 7:30 AM 2Q 1999	NOAA-N 870 km 1:40 PM 2000	ATMOS-A 500 km 45° Incl. 2000	FOO/CERES 705 km Low-mid inclination 2000	EOS PM-1 705 km 98.2° Incl. 1:30 PM 4Q 2000	METOP-1 850 km 9:00 AM 4Q 2000	ALOS 700 km 10:30 AM 1Q 2001	ISSA 51.6° Incl. 2001
Status	APPROVED					PLANNED	APPROVED		PROPOSED	PROPOSED	APPROVED
VIS/IR Imagers			GLI, POLDER	AVHRR/3	AVHRR/3	VIS/IR Imager		MODIS	AVHRR/3 AATSR	AVHRR-2	
Radiation Budget						CERES	CERES	CERES (2)	ScaRaB		
Passive Atmospheric Sounding				AMSU-A 1/2, AMSU-B HIRS/3	AMSU-A 1/2, MHS HIRS/3			AIRS, MHS, AMSU	IASI, HIRS/3, AMSU-A, MHS		
Passive Microwave	AMR		AMSR			TMI		MIMR	MIMR		
Active Microwave			SeaWinds			PR-2 CR			ASCAT	VSAR	
Tropospheric Chemistry											
Stratospheric Chemistry			ILAS-2		SBUV/2				GOMI		SAGE III
Radar Altimeter	SSALT										
Laser Altimeter											
Other	POD (DORIS)	ACRIM	DCS	SEM, ARGOS, S&R	SEM, ARGOS, S&R				ARGOS, SEM, S&R	DCS	
Operational Instruments				All Sensors	All Sensors				AVHRR/3, MHS, SEM, AMSU-A, HIRS/3, S&R, ARGOS		
Tropospheric Wind Lidar		*Solid-state laser technology development is under way in support of this objective*									

Table 11c. **The International Earth Observing System (cont'd)**

PROPOSED INSTRUMENT CONFIGURATION 2002 - 2006											
OBJECTIVES	**EXPLORER -1** TBD 2002	**NOAA-N'** 870 km 1:40 PM 2Q 2002	**EOS CHEM-1** 705 km 98.2° Incl. 1:45 PM 4Q 2002	**FOO/SOLSTICE** TBD 2003	**EOS Laser ALT-1** 94° Incl. 3Q 2003	**EXPLORER-2** TBD 2004	**EOS AM-2** 705 km 98.2° Incl. 10:30 AM 2Q 2004	**EOS Radar ALT-2** TBD 2004	**FOO/ SAGE III** TBD 2005	**METOP-2** TBD 1:30 PM 4Q 2005	**EOS PM-2** 705 km 1:30 PM 4Q 2006
Status	PLANNED	A P P R O V E D				PLANNED	A P P R O V E D			PLANNED	APPROVED
VIS/IR Imagers		AVHRR/3					MODIS, MISR, EOSP, LATI				MODIS
Radiation Budget							CERES (1)				CERES (1)
Passive Atmospheric Sounding		AMSU-A 1/2, MHS HIRS/3									AIRS, MHS, AMSU
Passive Microwave								AMR			Passive Microwave
Active Microwave											
Tropospheric Chemistry			HIRDLS, TES								
Stratospheric Chemistry		SBUV/2	HIRDLS, MLS								
Radar Altimeter								SSALT			
Laser Altimeter					GLAS						
Other		ARGOS, SEM, S&R	ODUS	SOLSTICE				POD (DORIS)	SAGE III		
Operational Instruments		All Sensors									
Tropospheric Wind Lidar		*Solid-state laser technology development is under way in support of this objective*									

December 1998. ENVISAT-1 will contribute to environmental studies in land surface properties, atmospheric chemistry, aerosol distribution, and marine biology. The second satellite series, METOP, will fly an operational meteorological package and climate monitoring instrumentation in cooperation with EUMETSAT and NOAA. This series will take over morning operational satellite coverage from the NOAA POES system in the 2000 timeframe. EUMETSAT does not consider METOP to be formally part of IEOS, although EUMETSAT participates in the EO-ICWG.

Further European contributions to IEOS include provision of the Multifrequency Imaging Microwave Radiometer (MIMR) by ESA for flight on EOS PM-1; EUMETSAT's provision of the Microwave Humidity Sounder (MHS) for flight on the NOAA POES series; and NASA cooperation with the UK on the High-Resolution Dynamics Limb Sounder (HIRDLS) on EOS-CHEM-1. The EOS Radar Altimetry mission may be conducted jointly with France as a follow-on to TOPEX/Poseidon. European scientists participate in these and other instrument investigation teams. Finally, France and the U.K. are sponsoring several EOS Interdisciplinary Science Investigations (see *Interdisciplinary Science* section.)

Russia

The Russian Space Agency is providing the spacecraft, the 1998 launch, and operations for NASA's Stratospheric Aerosol and Gas Experiment III (SAGE III). Russia is also participating in the full range of SAGE III science team activities, and plans for their data system interconnectivity with EOSDIS are under study.

Canada

The Canadian Space Agency (CSA) is providing MOPITT for flight on EOS AM-1 and possible reflight on a flight of opportunity. This instrument will measure atmospheric carbon monoxide and methane. CSA is also sponsoring two of the EOS Interdisciplinary Science Investigations. In the Phase I time period, prior to EOS, CSA and NASA are cooperating on a Canadian synthetic aperture radar mission, Radarsat. The spacecraft, instruments, and ground segment will be provided by Canada, and NASA is providing the Radarsat launch (scheduled for September 1995) and a data acquisition station in Alaska.

Japan

Japanese contributions to IEOS include the ADEOS missions and co-sponsorship of the TRMM mission. The U.S. will supply some instruments for flight on the ADEOS spacecraft. Japan will supply the launch vehicle and precipitation radar for TRMM.

As the first launch of IEOS, Japan plans to launch the polar-orbiting ADEOS mission in 1996. The objectives of ADEOS include Earth surface, atmospheric, and oceanographic remote sensing. ADEOS will be launched into a sun-synchronous, 98.6° inclination orbit with an ~800-km altitude, and an equatorial crossing time of 10:30 a.m.

Agreements have been concluded between NASDA and NASA for the two U.S. instruments that will fly on ADEOS, and between NASDA and CNES for POLDER. The satellite will have a ground-track repeat cycle of 41 days, providing global OCTS coverage every three days and daily coverage (sampled) for AVNIR. ADEOS is designed for a three-year mission lifetime; ADEOS-II is expected to be launched in 1999.

ADEOS-II

ADEOS-II is a post-ADEOS polar orbiting Earth observation satellite. Its mission is to obtain Earth science data regarding the global water cycle.

In order to achieve this mission, two core instruments developed by NASDA will be flown: a microwave imaging radiometer named AMSR (Advanced Microwave Scanning Radiometer) and a wide-coverage visible-to-thermal-infrared multi-spectral optical imager named GLI (Global Imager). In addition, three instruments, ILAS-II, SeaWinds—a modified NSCAT—and POLDER, are to be developed and delivered to ADEOS-II by the Environment Agency of Japan, NASA/JPL, and CNES respectively. ADEOS-II also carries a DFata Collection System (DCS) payload, which is not only compatible with ARGOS but also has a newly designed message forwarding capability.

Japan is also providing ASTER for the EOS AM-1 mission and ODUS for the CHEM-1 mission.

TRMM

Conducted in cooperation with the U.S., TRMM is a joint NASA/NASDA mission with the major objective of measuring precipitation, undoubtedly the most difficult atmospheric variable to quantify, and the crucial driver of the hydrologic cycle and atmospheric dynamics. TRMM will measure the diurnal variation of precipitation in the tropics from a low-inclination orbit using a variety of sensors. The goal of this mission is to obtain a minimum of three years of significant climatological observations of rainfall in the tropics; in tandem with cloud models, TRMM observations will provide accurate estimates of vertical distributions of latent heating in the atmosphere.

NASA will provide the TRMM spacecraft, a microwave imager, a visible/infrared imager, a lightning imaging sensor, a radiation budget instrument, and instrument integration. Japan is providing a precipitation radar and the H-II rocket to launch the satellite in 1997. TRMM will have a 350 km, 35° orbit.

As a follow-on to TRMM, NASDA is considering a series called ATMOS (Atmospheric Observations Satellite). As the basis for Phase A studies, NASDA is considering that ATMOS-A would fly in a mid-inclination (45°, 500 km) orbit, and would make TRMM-type measurements. A subsequent ATMOS-B would focus on clouds and radiation in a polar, non-sun-synchronous orbit, and ATMOS-C would look at trace gases in the atmosphere in a 60°, 700-km orbit. All three satellites would be open to international sensor contributions.

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Interagency Coordination

Interagency Coordination

Interagency cooperation in the development and implementation of EOS continues to be extensive, especially among those agencies with space programs and/or significant responsibilities for archiving Earth science data. National Space Policy Directive #7 further cemented these agency relationships by establishing the Space-Based Global Change Observation System (S-GCOS) Program in June 1992. These activities are currently coordinated through the Task Force on Observations and Data Management of the CENR. The Task Force on Observations has the responsibility to ensure collection of comprehensive, integrated sets of consistent ground- and space-based observations; the space component of these activities has Mission to Planet Earth as its centerpiece. NASA's Mission to Planet Earth Program has been planned to benefit from and complement the capabilities of its Federal partners, which are listed below, with specific roles in EOS development defined in the following paragraphs:

- Department of Commerce/National Oceanic and Atmospheric Administration (DoC/NOAA).
- Department of Defense (DoD).
- Department of Energy (DoE).
- Department of the Interior/U.S. Geological Survey (DoI/USGS).

Department of Commerce

NOAA conducts U.S. civil programs for operational Earth remote sensing. Since 1960, satellite observations of the global environment have been provided by NOAA's Polar-orbiting Operational Environment Satellite (POES) system. Coverage of the Western Hemisphere has been provided by NOAA's Geostationary Operational Environmental Satellite (GOES) system since 1974. The current and future satellites of the POES and GOES systems are an essential part of the USGCRP. These satellites provide valuable precursor data, and will yield complementary observations during the EOS mission lifetime. Furthermore, NOAA's long-term data record will be used to establish baseline conditions and to detect trends.

The present POES Program maintains two operational satellites in polar orbit—one providing morning (AM) coverage and the other afternoon (PM) coverage. The U.S. and Europe, i.e., EUMETSAT and ESA, have agreed in principle that Europe will take over responsibility for the AM global coverage mission in the 2000 time frame. NOAA will provide AM coverage through 2000, and will continue PM coverage. Through NOAA, the U.S. will provide a suite of four primary sensors for the European AM mission. EUMETSAT and others will reciprocate by supplying sensors and subsystems for flight on both the AM and PM satellites.

Planning for the cooperative program of global coverage by the U.S. and Europe includes arrangements to fly the NOAA/EUMETSAT operational payload in morning orbit and EUMETSAT's establishment of a high-latitude ground station to read out data from both the AM and PM platforms. This latter agreement ensures that data are downlinked each orbit, minimizing data latency and dependence on data averaging. With one European and two U.S. high-latitude stations, NOAA and EUMETSAT will essentially eliminate data delays associated with the recording of multiple or "blind" orbits. NOAA and EUMETSAT have agreed to establish systems and procedures to ensure the timely and full exchange of operational mission data.

Long-term improvements in NOAA satellite, instrument, and space subsystem design are expected to result from technology advances associated with the EOS Program. To this end, coordination in technology development extends to NASA's designating some EOS instruments as "prototypes" for future operational environmental satellites. This means that NOAA and NASA are agreeing on design features that would enable these prototypes to be transferred to NOAA spacecraft after being space-proven in NASA research/demonstration efforts. Furthermore, NASA has been designated by the President as playing a lead role in the identification and promotion of new technology for the future converged National Polar Orbiting Environmental Satellite System (NPOESS), working with DoD and NOAA in the Integrated Program Office (see below).

Data products derived from POES and GOES observations are provided to users in real-time and from archived data sets by NOAA; in addition, Pathfinder data sets are provided jointly by NASA and NOAA (see the *Pathfinder Data Sets* section). As a participant in the EOSDIS Program, NOAA will serve as the long-term archive for a major portion of EOS data, and will continue to make available in situ data from its data centers. NOAA actively participates in EO-ICWG and the Committee on Earth Observation Satellites (CEOS); in addition, NOAA chairs the Interagency Working Group on Data Management for Global Change (IWGDMGC), where interagency data exchange arrangements and policies are planned and coordinated.

Because of a reassessment by the National Science and Technology Council, the Landsat-7 program has been reassigned from a joint DoD and NASA program to a joint NASA, NOAA, and USGS program. This was done by Presidential Decision Directive NSTC-3 dated May 5, 1994. This directive stipulates that NASA, NOAA, and the USGS are to proceed with the procurement, launch, and operation of Landsat-7 begun under the DoD and NASA program. The program objectives are to provide data continuity with previous Landsats, to implement a Data Policy Plan making data available to all users at the cost of fulfilling user requests, and to develop a plan for acquiring follow-on Landsat-type data as a part of the EOS Program.

Department of Defense

DoD's Defense Meteorological Satellite Program (DMSP) maintains satellites in polar orbit to gather global environmental data. DMSP data and derived products have been made available to non-DoD users through NOAA. DoD will continue DMSP into the foreseeable future, and DMSP data will be available to global change researchers in standard formats via global change data networks.

Currently under negotiation is a Memorandum of Agreement among NOAA, NASA, and DoD which will converge DoD's DMSP and NOAA's POES program. NASA's EOS efforts offer new remote sensing and spacecraft technologies that could potentially improve the capabilities of the operational system. The converged system is a result of Presidential Decision Directive/NSTC-2, signed by President Clinton on May 5, 1994.

DoD plans future satellites and instruments that will provide additional Earth system observations. Missions under consideration address ocean conditions, ozone and trace gas distributions, ionospheric airglow, and solar energy interactions with the atmosphere. DoD participates in planning for USGCRP and its associated data systems. In cooperation with the other Federal agencies involved in EOSDIS and related data systems, DoD is seeking workable approaches to make more of its relevant data available. Other working groups are being established to explore potential environmental remote-sensing collaborations between NASA and DoD.

DoD plans to launch the Midcourse Space Experiment (MSX) satellite in 1995. It will collect spatial and spectral data, including spectra of atmospheric emissions from near the Earth's surface to tangent heights in excess of 100 km. The spectral data will cover the visible and ultraviolet from 110 to 900 nm and the infrared from 2.6 to 28 μm. The data will normally be available to the non-DoD science community after two years, under the provisions of the MSX data release policy, but can be made available sooner through special arrangements.

NASA is interested in collaborating with this DoD program in order to supplement data being collected by the Upper Atmosphere Research Satellite (UARS) and other NASA observational platforms, and as a pathfinder for the EOS satellites.

Department of Energy

DoE develops and uses remote-sensing technology in many of its programs. The agency develops and tests climate models, and assesses the impacts associated with incidental environmental forcing functions. For instance, DoE has conducted a decade-long program to improve general circulation models and to provide reliable predictions of regional climate change in response to increases in atmospheric greenhouse gases. DoE holds databases acquired from a multitude of sources as tools for conducting its modeling and climate-prediction activities.

With respect to hardware, DoE has successfully miniaturized key components of space-based instrumentation, which adds a great deal of flexibility to Earth remote-sensing programs. Recent developments now enable the deployment of low-mass, low-volume sensors on conventional or small satellites. Miniaturization technology contributes to the effectiveness of USGCRP by allowing early deployment of small satellites. In an effort to exploit such technology advances, NASA and DoE have created a Joint Development and Demonstration Program in Advanced Remote-Sensing Technology, which has the objective of lowering the cost and improving the performance of remote sensors. The ultimate goal involves the development of remote-sensing technologies and concepts for space-based environmental applications. Four areas are currently under investigation: Laser detection of winds, high-resolution multispectral imaging, synthetic aperture radar, and unmanned aerospace vehicle (UAV) sensing.

The DoE'S Atmospheric Radiation Measurement (ARM) program presents an important opportunity for collaboration between DoE and EOS. The role of ARM is to provide intensive ground-based measurements of atmospheric properties at a few selected heavily instrumented sites. This DoE activity then presents a significant source of "ground truth" for calibration and validation of EOS space-based observations.

At present the Southern Great Plains site is the first to be occupied, with plans to develop a second site in the tropical Western Pacific and a third in Alaska later. The sites have been chosen to provide a sampling of continental (Southern Great Plains), tropical oceanic (tropical Western Pacific) conditions of clouds and radiation, and the radiation environment, and the influence of clouds under polar conditions (North Slope of Alaska).

ARM is supporting a program of unmanned aircraft (UAVs) that will serve as the platforms for relatively inexpensive instruments whose measurements will validate the radiation modeling for the atmosphere at the various ground-instrumented sites.

Along with the involved U.S. agencies, DoE is developing the networking capabilities to make its current and future global change archives more conveniently accessible to users. In the EOSDIS framework, DoE has agreed to manage the EOS biogeochemical dynamics database, and data from coordinated field experiments. This database will reside at the Oak Ridge National Laboratory (ORNL).

Department of the Interior

Management responsibility for the Nation's natural ecosystem, energy and water resources, and public lands is vested in DoI. Within DoI, USGS is addressing the collection, maintenance, analysis, and interpretation of *in situ* short- and long-term land, water, biological, and other natural resource data and information. USGS is developing advanced information systems to provide enhanced access to existing and future archives of Earth science data through its primary archive for global change data—the Earth Resources Observation System (EROS) Data Center (EDC).

EDC houses the world's largest collection of space- and aircraft-based imagery of the Earth's land surface, including over 2 million images acquired from Landsat and other satellites, and over 8 million aerial photographs. As part of the EOS Program, EDC is responsible for the following:

- operating the data center responsible for land processes information,
- communicating with the EOS science and instrument teams to ensure delivery of land-related products required for EOS investigations, and
- linking the USGS Global Land Information System (GLIS) to the EOSDIS Information Management System (IMS).

GLIS—an on-line data directory, guide, and inventory system—is being developed by USGS to respond to the land data and access needs of the global change research community.

By the time of the EOS AM-1 launch in 1998, Landsat data housed at EDC will provide a 25-year baseline of information about land surface conditions and changes. As the operator of the National Satellite Land Remote-Sensing Data Archive, USGS has embarked upon a major program to convert the Landsat data archive to next-generation durable storage media, thereby avoiding loss of data stored on deteriorating magnetic tapes. In addition, EDC will serve as the processing, distribution, and archival facility for Landsat-7 data.

Interagency Convergence

A Presidential Decision Directive has been signed, which directs the convergence of the civil and military polar-orbiting environmental programs into a single integrated system. This consolidation was a key recommendation of the National Performance Review. The goal of the converged program is to reduce the cost of acquiring and operating polar-orbiting operational environmental satellites, while continuing to satisfy U.S. operational civilian and national security requirements.

Convergence of the follow-on satellite programs of the Department of Commerce, National Oceanic and Atmospheric Administration's (NOAA) Polar-orbiting Operational Environmental Satellite (POES) program, and the Department of Defense's Defense Meteorological Satellite Program (DMSP) has already begun under the aegis of an Integrated Program Office (IPO) jointly staffed by NOAA, DoD, and NASA personnel. As part of the goal of reducing costs while enhancing the ability of the converged system to meet its operational requirements, the operational program will incorporate aspects of NASA's Earth Observing System where and as appropriate.

The POES satellites currently provide the civilian environmental monitoring. Key aspects of the POES mission include collecting atmospheric data to be used in conjunction with computer models for weather forecasting, measuring global ozone levels for climate change research, and monitoring emergency beacons for search and rescue operations. The purpose of the DMSP program is to collect and disseminate global visible and infrared cloud data and other specialized meteorological, oceanographic, and solar geophysical data to provide a survivable capability in support of military operations. Some of these observations form the bases of the NASA-NOAA Pathfinder Data Set Program (see *Pathfinder Data Sets* section of this Handbook).

The U.S. currently operates two NOAA POES and two DMSP meteorological satellites in polar orbit. Through convergence the U.S. will transition to an on-orbit architecture of three low-Earth orbiting satellites. Current plans call for the on-orbit constellation to comprise two U.S. satellites as well as a third European satellite (METOP), carrying U.S. and European operational and research instruments. The METOP series is a joint undertaking of the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and the European Space Agency (ESA). Significant savings will be gained through the reduction of the required number of U.S. satellites from four to two, the transition to a converged U.S. spacecraft, and the near-term efficiencies of consolidating the command and control activities of the current operational spacecraft over the next few years.

The National Science and Technology Council

The NSTC is a standing, cabinet-level body chaired by the President and composed of the Vice President, the Assistant to the President for Science and Technology, the cabinet secretaries and agency heads with responsibilities for significant science and technology programs, and other White House officials. The principal purposes of the NSTC are to define clear national goals for federal science and technology investments and ensure that science, space, and technology policies and programs contribute effectively to the national goals.

In 1994, NSTC committees identified R&D priorities, and the NSTC, through the Office of Science and Technology Policy and the Office of Management and Budget, provided federal agencies with coordinated budget guidance for Research and Development.

In recent years, there have been a number of thoughtful criticisms of the way the federal government has historically conducted environmental R&D. The piecemeal, single-issue-by-single-issue, agency-by-agency research programs once thought to be adequate to deal with the environment have been widely recognized as inadequate to deal with the complex air, land, sea, economic, and social issues associated with regional, national, and global concerns such as ocean transport of pollutants, atmospheric deposition, climate change and ozone-layer depletion, biodiversity, and sustainable development. Ensuring economic development in concert with environmental protection makes the need for stronger integration of social, economic, and environmental sciences critical as all stakeholders are drawn into the process of environmental decision making. The NSTC Committee on Environment and Natural Resources (CENR) was created as a new way to conduct coordinated, cost-effective, interdisciplinary research to address the important environmental issues of our time.

CENR has emphasized research to understand the potential consequences of long-term environmental change and to promote the efficient use of natural resources while sustaining ecosystems for future generations. Increased emphasis has been placed on the integration of social sciences and assessment end points into research planning in all of the CENR issue areas.

Efforts are being made throughout the CENR, with coordination by the Task Force on Observations and Data Management, to increase the efficiency with which the vast array of monitoring and other forms of data generated within the federal system are made available. This process will help to better define where true gaps in long-term monitoring exist and need to be filled.

The CENR consists of seven issue subcommittees created because they represent areas of important policy that transcend the interest of a single agency: Global Change; Biodiversity and Ecosystem Dynamics; Resource Use and Management; Water Resources and Coastal and Marine Environments; Air Quality; Toxic Substances and Hazardous and Solid Waste; and Natural Disaster Reduction.

The CENR has three crosscutting subcommittees: Risk Assessment, Social and Economic Sciences, and Environmental Technology (a joint subcommittee of CENR and the NSTC Committee on Civilian and Industrial Technology). The crosscutting subcommittees focus on themes common to the areas covered by the seven issue subcommittees and provide an additional mechanism for interagency coordination. Risk assessment, for example, plays an important role in issues such as the effects of toxic substances, biodiversity, loss of ecosystem integrity, natural disaster reduction, and effects of global change on human health and ecosystem function. Social and economic sciences are critical to evaluating the impacts of human activities on local, regional, and global environments and human responses to natural disasters and environmental change. The Task Force on Observations and Data Management coordinates requirements and capabilities in these areas across the CENR research issues.

The CENR has identified the following five priority areas that cross all environmental R&D:

- **Ecosystem research**—to promote efficient use of natural resources while sustaining ecosystem integrity for future generations.

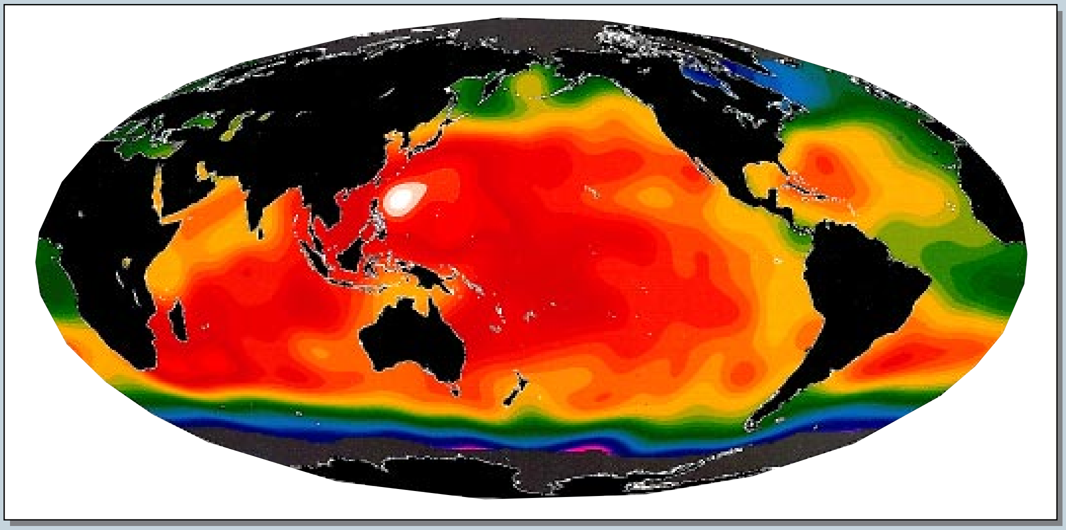
- **Observations and data management**—to ensure that the necessary measurements are made efficiently and that the data are widely available to all stakeholders in easily usable forms.

- **Socioeconomic dimensions of environmental change**—to understand the underlying human influences on the environment and the potential responses of society to change.

- **Environmental technology**—to protect the environment while stimulating economic growth and capturing emerging global markets.

- **Science policy tools**—to provide the tools, e.g., integrated assessment and risk models, required by policy makers for informed decisions on complex environmental and societal issues.

TOPEX/Poseidon



Shown is an observation of sea level made by the TOPEX/Poseidon satellite. The map represents the seasonal deviation of sea level from its annual mean.

This first global view of the oceans is possible because TOPEX/Poseidon measures the global sea-level variability with unprecedented accuracy. The error along a single-orbit measurement is estimated to be less than 5 cm. The seasonal cycle is thus determined with an accuracy better than 2 cm. After several years of observations oceanographers will create a very precise description of the seasonal cycle of the world surface circulation. Equally important are the year-to-year changes to the seasonal cycle. Incorporating these data into global ocean models will lead to a much better understanding of the ocean's role in climate change.

The maximum sea level is located in the Western Pacific Ocean (white) and the minimum is shown around Antarctica (blue and purple). In the Northern Hemisphere, ocean currents flow clockwise around the highs of ocean topography and counter-clockwise around the lows. This pattern is reversed in the Southern Hemisphere, These highs and lows are oceanic counter-parts of atmospheric circulation systems. The existence and basic structure of the ocean systems are constant, but the details of these systems are always changing. These features can therefore be considered the "climate" of the ocean.

Mission Elements

Mission Elements

This section provides specifics on the space-based elements that make up the International Earth Observing System (IEOS). Refer to Figure 6 for a schedule of ongoing and planned U.S. and international partner Earth-observing missions. This timeline is not confined to IEOS; rather, it provides a fairly comprehensive listing of relevant Earth remote-sensing satellites, many of which do not receive attention in the following pages. The timeline intentionally encompasses missions beyond the scope of IEOS to show how IEOS fits into the larger scheme of Earth observations satellites. Given the long planning schedule (over ten years shown), this chart should be considered more of a planning document, accurate through 1995.

The following mission descriptions correspond to Tables 11a through 11c in the *International Cooperation* section. Each space-based element makes unique contributions to overall IEOS objectives, so the order of discussion should not connote a ranking or prioritization of any kind:

- Earth Observing System (EOS) missions
- Japanese Advanced Earth Observing System (ADEOS) missions
- Japanese/U.S. Tropical Rainfall Measuring Mission (TRMM)
- European ENVISAT/METOP satellites
- Polar-Orbiting Operational Environmental Satellite (POES) series

For the sake of brevity, instrument acronyms are not defined herein (see *EOS Acronyms* at the end of this Handbook).

EOS Missions

EOS is a long-term program to provide continuous observations of global climate change. Repeating flights of the principal EOS spacecraft on 6-year centers will ensure adequate coverage for at least 15 years; however, payloads of the follow-on EOS spacecraft could change, depending on the evolution of scientific understanding and the development of technology.

The EOS Program currently includes one intermediate and eight medium-sized spacecraft—three of which will be morning sun-synchronous (EOS AM series), three afternoon sun-synchronous (EOS PM series), and three afternoon sun-synchronous polar (EOS CHEM series). The EOS AM, PM, and CHEM spacecraft will be placed into 98.2° inclined, 705-km, 16-day, 233-orbit repeat cycles, with the EOS AM series having a 10:30 a.m. descending nodal crossing, the EOS PM series a 1:30 p.m. ascending nodal crossing, and the EOS CHEM series a 1:45 p.m. ascending nodal crossing. Three smaller spacecraft (medium light) of the EOS Radar ALT series will be placed into non-sun-synchronous high-inclination orbits (66°, same as TOPEX), and medium-light spacecraft of the EOS Laser ALT series will be placed into non-sun-synchronous orbits at a 94° inclination. The SAGE III series will be placed into a high-inclination orbit on the Meteor 3M-1 spacecraft and into a mid-inclination (57.1°) orbit on the Space Station.

All but one of the spacecraft in each of the three primary series will be functionally identical, with only minor changes expected in the measurement complements. EOS AM-1 is the only exception. The rescoping deliberations resulted in the initiation of a common spacecraft bus design to reduce total

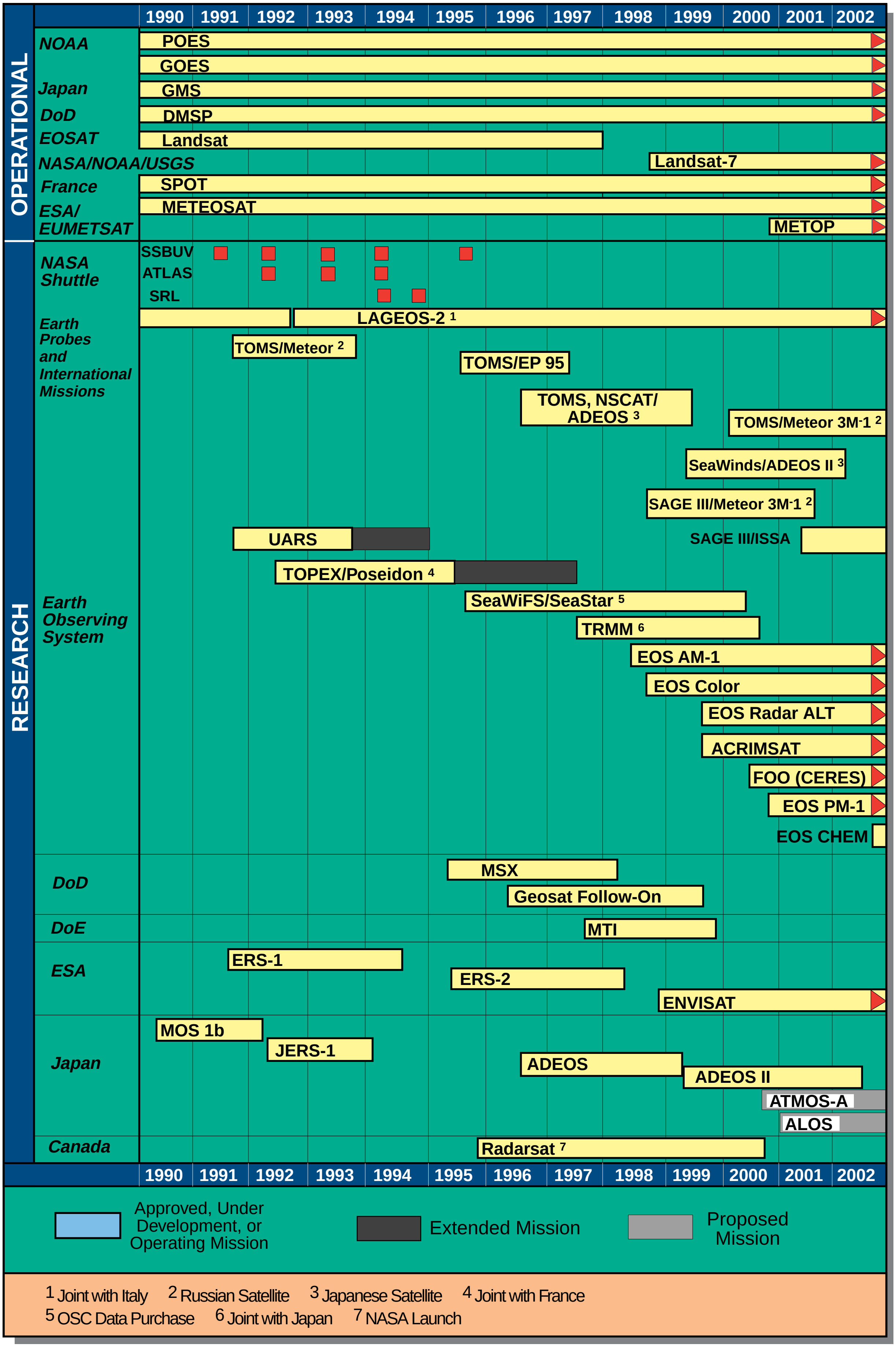


Figure 6. **U.S. and International Partner Earth-Observing Missions**

program cost (see the *EOS Program* section for more detail). It was decided that adhering to the current EOS AM-1 development schedule provided the greatest assurance of meeting the June 1998 launch readiness date. As such, the EOS PM-1 instrument complement will be the first to be integrated onto the common spacecraft bus, which will be used on at least the first of the EOS PM and CHEM missions. Ocean primary productivity observations are being obtained via a data purchase from the Sea-Viewing Wide Field-of-view Sensor (SeaWiFS), which is scheduled for launch onboard SeaStar in 1995. Figure 7 illustrates the rebaselined program-level architecture (see also Figure 4, *EOSDIS Architecture*, in the *EOSDIS* section).

As stated earlier in this Handbook, the presence of MODIS on both the EOS AM and PM spacecraft proves central to the program by providing complete global ocean color measurements through avoidance of sun glint over the northern oceans and the lack of illumination over the southern oceans. By taking further advantage of the complementary ascending and descending orbits of the AM and PM spacecraft, MODIS provides diurnal sampling coverage and also provides the cloud observations needed to interpret CERES radiation budget measurements, which are also collected by both spacecraft.

SAGE III will provide observations of aerosols and temperature from two different orbits.

The descriptions that follow of the EOS satellite series emphasize the first platform in the series, since requirements may change as the program evolves. Detailed descriptions of all instruments that remain as part of the rebaselined EOS Program can be found in the *EOS Instruments* section of this Handbook.

Direct Broadcast

While the majority of the EOS data users are expected to obtain their data from the EOSDIS, real-time MODIS data from the EOS AM series of spacecraft, as well as the entire real-time data stream of the EOS PM series of spacecraft, will be broadcast directly to the ground and available to anyone within line-of-sight of these spacecraft. These data may be received, without charge, by anyone who has obtained or constructed an appropriate ground station.

This Direct Broadcast service will require a moderately sophisticated ground station capable of receiving the signal (a tracking 3-m dish antenna operating in the X-band of 8025-8400 MHz), capturing the data (at a rate of 13.125 Mbps for EOS AM-1, and slightly higher for the PM series), and providing all the data processing necessary to produce a usable product. NASA will provide the information necessary to procure, or build, and operate such a station, but has no responsibility to provide the funding to do so.

ADEOS and ADEOS-II will transmit extracted OCTS/GLI data at UHF (467 MHz).

EOS AM Series

Planned for launch in June 1998, the EOS AM-1 flight includes five instruments to be placed into a polar, sun-synchronous, 705-km orbit by an Intermediate Expendable Launch Vehicle (IELV). The launch will take place from the U.S. Air Force Western Space and Missile Center (WSMC). The payload consists of ASTER, CERES (dual scanner), MISR, MODIS, and MOPITT.

EOS AM-1 will have an equatorial crossing time of 10:30 a.m., when daily cloud cover is typically at a minimum over land such that surface features can be more easily observed. The instrument complement is intended to obtain information about the physical and radiative properties of clouds (ASTER, CERES, MISR, MODIS); air-land and air-sea exchanges of energy, carbon, and water (ASTER, MISR, MODIS); measurements of important trace gases (MOPITT); and volcanology (ASTER, MISR, MODIS). CERES, MISR, and MODIS are provided by the U.S.; MOPITT is provided by Canada; and ASTER is provided by Japan. The EOS AM-1 spacecraft design (see Figure 8) will support an instrument mass of 1,155 kg, an average power for spacecraft and instruments of 2.5 kW (3.5 kW peak), and an average data rate of 18 Mbps (109 Mbps peak). Onboard solid-state recorders will collect at least one orbit's data for playback through TDRSS, even though a playback on each orbit is planned.

The current mission plan includes three AM flights—EOS AM-1 to be launched in June 1998, EOS AM-2 in June 2004, and EOS AM-3 in June 2010. NASA is currently conducting a study to ex-

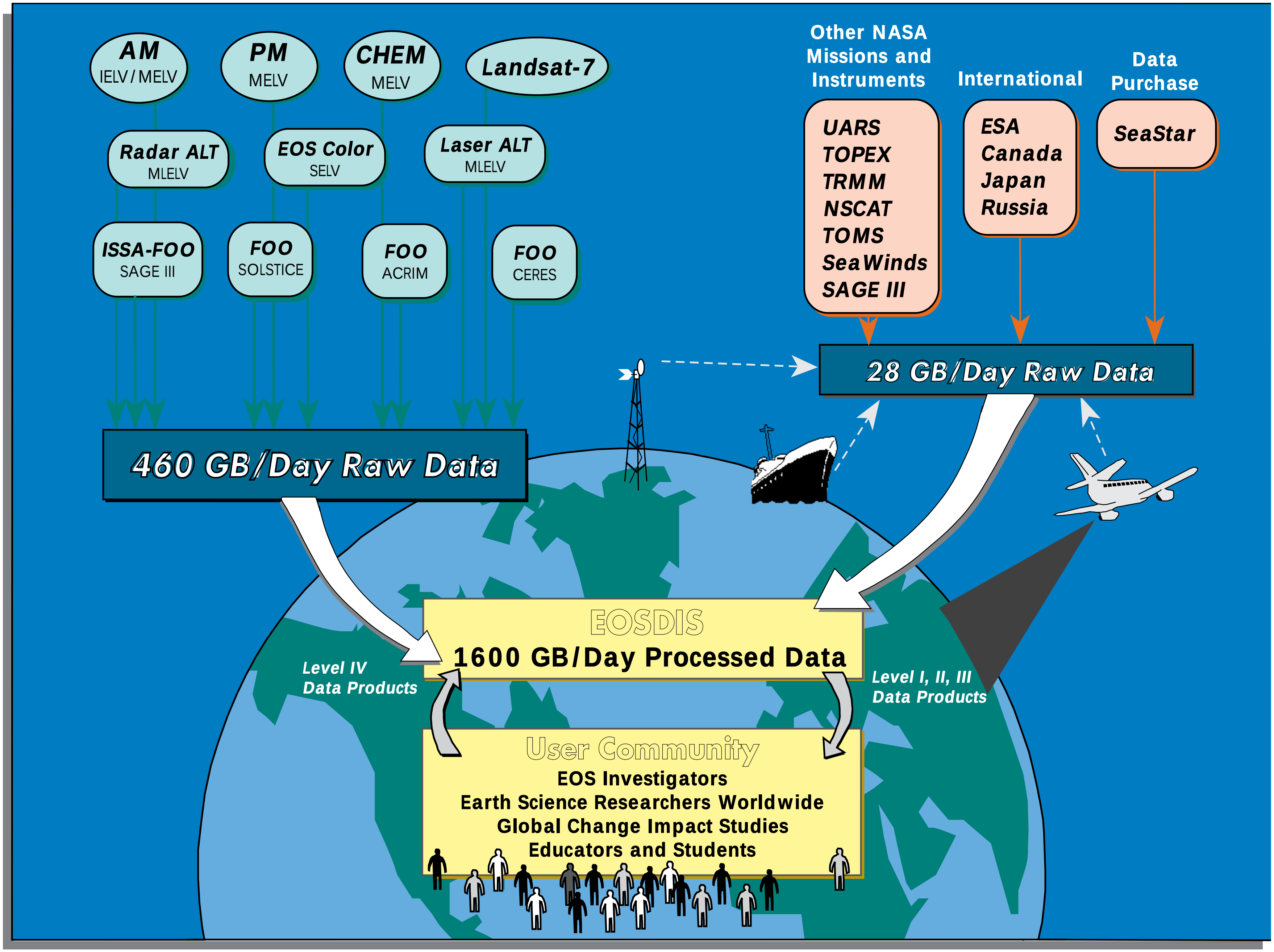


Figure 7. EOS Rebaselined Program Level Architecture

amine alternative strategies for carrying out the AM-2 and AM-3 missions. The objective is to benefit from technological advances being made in the small satellite arena to reduce the overall life-cycle cost of the program, while maintaining the commitment to provide continuity of critical observations to be provided by the EOS AM-1 mission.

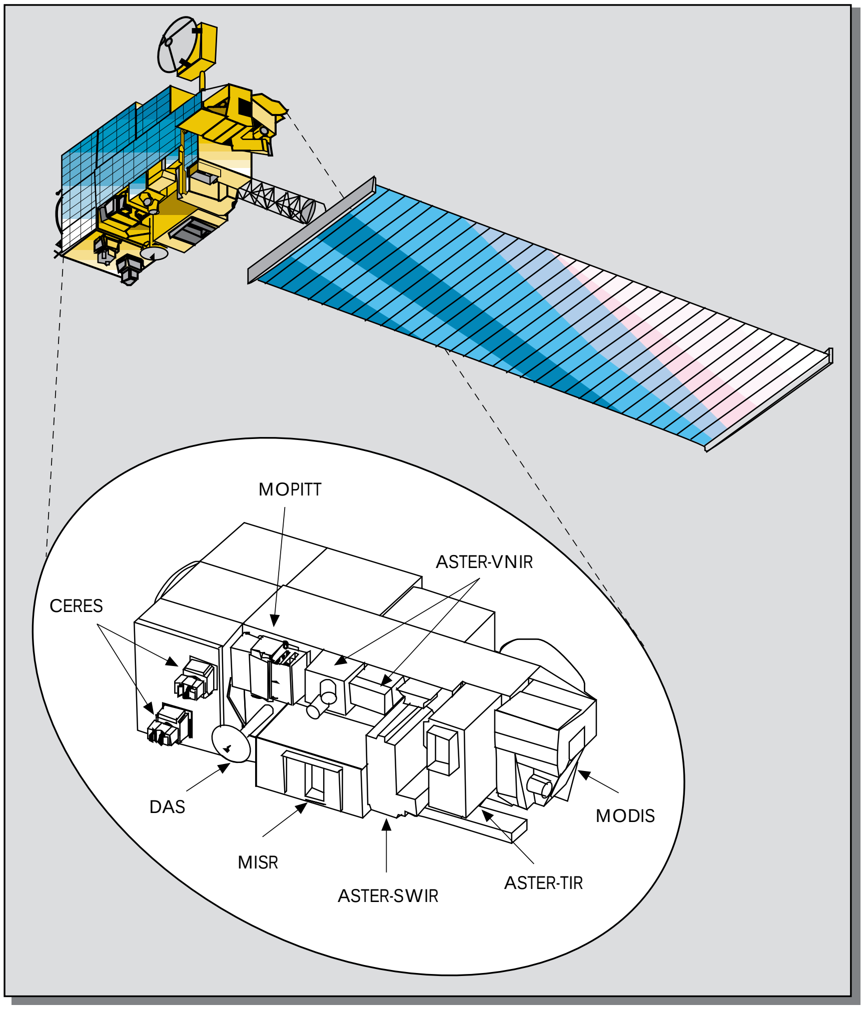


Figure 8. **The EOS AM-1 Satellite and Payload**

The EOS AM-1 spacecraft will also include the Direct Access System (DAS), which is composed of the Direct Playback (DP) subsystem, the Direct Broadcast (DB) subsystem, and the Direct Downlink (DDL) subsystem. AM-1 data will be recorded and played back via TDRSS, and DAS will provide a backup option for direct transmittal of onboard data to ground receiving stations via an X-band transmitter (DP subsystem) should the satellite lose its TDRSS link. DAS will also support transmission of data to ground stations of qualified EOS users around the world who require direct data reception. These users fall into three categories:

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

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

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

The DB subsystem will broadcast MODIS data at 13 Mbps. At this rate, properly equipped ground stations can receive, process, and display the swath data as the EOS spacecraft passes within range.

EOS PM Series

Current plans call for EOS PM-1 to be launched in December 2000. This satellite series will include six instruments to be placed into a polar, sun-synchronous, 705-km orbit. The EOS PM instrument complements will be integrated onto the common satellite bus described earlier, with the spacecraft boosted into orbit by a Medium Expendable Launch Vehicle (MELV) launched from WSMC. The payload consists of AIRS, AMSU, MHS, CERES, MIMR, and MODIS. The EOS PM series spacecraft will have an afternoon crossing time to enhance collection of meteorological data by the atmospheric sounders onboard. The instrument complement is designed to provide information on cloud formation, precipitation, and radiative properties (AIRS, AMSU, MHS, CERES, MODIS); air-sea fluxes of energy, carbon, and moisture (AIRS, AMSU, MHS, MIMR, MODIS); and sea-ice extent (MIMR, MODIS). AIRS, AMSU, CERES, and MODIS are provided by the U.S.; MHS and MIMR will be provided by ESA or other agencies. The EOS PM series spacecraft will include the DB and DP capabilities of DAS (see the *EOS AM Series* write-up), with the DB subsystem transmitting all instrument data.

Currently, the plan is for all EOS PM satellite instrumentation to be identical, except that CERES will consist of two scanners on EOS PM-1 and a single scanner on the follow-on flights. Also, the MIMR on EOS PM-1 will probably be replaced by a similar Passive Microwave Radiometer on subsequent PM missions. EOS PM-2 is scheduled for launch in December 2006, followed by EOS PM-3 in December 2012. The EOS PM spacecraft design will support an instrument mass of 1,100 kg, average power for the instruments of 1,200 W (1,630 W peak), and an average data rate of 7.7 Mbps (12.5 Mbps peak).

Discussions are under way with NOAA to identify common observational capabilities between PM-2 and the NOAA Polar Orbiting Environmental Satellite with the afternoon nodal crossing time. To the extent that such common capabilities can be identified, the EOS PM-2 mission may be modified; however, the continuity of basic observations beyond the PM-1 mission remains as a major commitment by NASA.

SAGE III Series

The EOS AERO series discussed in the 1993 EOS Reference Handbook (flying only SAGE III instruments) has been renamed the "SAGE III series." A SAGE III instrument will be placed into a high-inclination orbit on a Russian Meteor 3M-1 spacecraft in 1998 and into a mid-inclination orbit (51.6°) on the International Space Station Alpha (ISSA) beginning in 2001. A combination of high- and low-inclination orbits is required to optimize collection of occultation data at all latitudes. SAGE III will make long-term trend measurements of aerosols, ozone, water vapor, and clouds from the middle troposphere through the stratosphere—important parameters for radiative and atmospheric chemistry models.

EOS Altimetry

The original EOS Altimetry mission has been split in accordance with a recommendation by the EOS Payload Panel in 1994 that there be two separate spacecraft missions because of different orbital requirements for different science missions: one for ocean circulation studies, EOS Radar Altimetry (EOS Radar ALT); and one for ice-sheet mass-balance studies, EOS Laser Altimetry (EOS Laser ALT).

EOS Radar Altimetry Series (EOS Radar ALT)

The global sea surface topography measurements currently being provided by the TOPEX/Poseidon mission are of unparalleled accuracy and are providing a critically needed ability to monitor accurately the global oceans at a temporal resolution of 10 days. These data provide new opportunities for monitoring ocean phenomena and developing models to predict long-term global change. It is imperative that this measurement series be continued beyond the current TOPEX/Poseidon mission. The following two options are currently being explored for the EOS Radar ALT series:

1) *A TOPEX/Poseidon Follow-On (TPFO)*—This mission would be conducted jointly with Centre National d'Etudes Spatiales (CNES) and NOAA. TPFO would be flown in the same 66° inclination non-sun-synchronous orbit as TOPEX/Poseidon.

2) *A Geosat Follow-On (GFO)*—This mission, developed by the U.S. Navy, would have required several changes in order to meet EOS Science Objectives. The most important of these would have been the addition of a dual-frequency altimeter (DFA) to correct for ionospheric retardation of the radar signal.

NASA and the U.S. Navy conducted a joint study to evaluate the ability of each option to meet the NASA requirement in support of global change research and the Navy operational requirements. It was found that option 1 can meet the NASA requirements and, with minor modification, by allowing the encryption of data in time of national emergency and the ability to downlink directly observations to ships and submarines, it can also meet U.S. Navy requirements. Option 1 has also the unique feature of continuing an international partnership with France, resulting in a reduced overall mission cost to NASA.

EOS Laser Altimetry Series (EOS Laser ALT)

The EOS Laser ALT mission will fly the Geoscience Laser Altimeter System (GLAS) instrument. GLAS is a solid-state neodymium: yttrium-aluminum-garnet (Nd : YAG) laser altimeter, including integral star trackers and Global Positioning Systems (GPS) for precise altitude and orbit determinations. The GLAS science objectives are ice topography and mass balance measurements, and, secondarily, land, vegetation, and cloud elevation. EOS Laser ALT will be flown in a 94° non-sun-synchronous orbit.

EOS CHEM Series

The EOS CHEM series will employ the same common spacecraft bus that will be used for the EOS PM flight. The rebaselining of the EOS Program has had a significant impact on this mission. SAGE III was removed and assigned its own series. ACRIM and SOLSTICE (which had been added in late 1992) were also removed. ACRIM was assigned its own series of ACRIMSATs, and SOLSTICE was assigned to a Flight of Opportunity (FOO) that now will be accommodated by a joint U.S.-Canada small-satellite mission. TES (which had been moved from CHEM-1 to AM-2/3 in 1992) was moved back to the CHEM mission. A Japanese instrument had been added to the CHEM mission in late 1992, in reciprocation for the flight of SeaWinds on the Japanese ADEOS II mission. The Japanese instrument had been referred to by the generic name Chemistry International Instrument (CII) and has now been named Ozone Dynamics Ultraviolet Spectrometer (ODUS).

The instrument complement for CHEM-1 now consists of MLS, TES, HIRDLS, and ODUS. CHEM will be launched on an MELV into a 705-km, sun-synchronous orbit. The first launch is slated for 2002, with the follow-ons to be launched in 2008 and 2014. EOS CHEM instruments will provide measurements of ozone, chlorine monoxide, hydroxyl radical, and water vapor (MLS), practically all infrared-active species from the Earth's surface to the lower stratosphere (TES), atmospheric trace gases (HIRDLS), and total ozone, in addition to detecting sulfur dioxide and nitrogen dioxide (ODUS).

EOS Special Missions

In addition to the six primary types of EOS missions discussed above, there are special missions, usually flown on small satellites, whose objectives may require only a one-time flight or involve unique characteristics such as an unusual orbit or a highly specialized type of measurement. A series of small ACRIMSATs, carrying the ACRIM instrument, is scheduled to acquire total solar irradiance measurements without interruption over a period of 15 years, beginning in 1999. The CERES instrument is also scheduled on a separate one-time Flight of Opportunity (FOO) in 2000 in a unique low-mid-inclination, non-sun-synchronous orbit to acquire diurnal measurements not possible from the AM and PM missions. The Japanese ATMOS-B satellite is a potential candidate for flight of CERES. The SOLSTICE instrument is currently scheduled on a FOO in 2003 to acquire high-spectral-resolution measurements of solar ultraviolet irradiance, important in understanding corresponding changes in the photochemistry, dynamics, and energy balance of the middle atmosphere.

ADEOS Missions

Japan plans to launch the polar-orbiting ADEOS mission in August 1996. The objectives of ADEOS include Earth surface, atmospheric, and oceanographic remote sensing. ADEOS will be launched into a sun-synchronous, 98.6° inclination orbit with an ~800-km altitude, and an equatorial crossing time of 10:30 a.m. The satellite will have a ground-track repeat cycle of 41 days, providing global OCTS coverage every 3 days and daily coverage (sampled) for AVNIR. ADEOS is designed for a 3-year mission lifetime; ADEOS-II is expected to be launched in 1999. ADEOS will fly the following instruments:

AVNIR—Five visible/near-infrared bands (0.420 to 0.890 µm); 16- or 8-m resolution; 80-km swath; ±40° across-track pointing; stereo capability; observation of sunlight reflected by Earth's surface (developed by NASDA).

ILAS—Infrared occultation device; one visible band at 0.753-0.784 µm, and one infrared band at 6.21-11.77 (16-cm^{-1} resolution); 2-km IFOV; observations from 10-60 km, approximately 2-km vertical resolution expected; retrieval of stratospheric ozone and related species at high latitudes (provided by Japan's Environmental Agency).

IMG—Nadir-looking Fourier transform infrared spectrometer; range 3.3-14.0 µm, with a spectral resolution of 0.1 cm^{-1}; ~8 km^2 foot print; vertical resolution ~2-6 km depending on species; observation of carbon dioxide, methane, and other greenhouse gases (provided by MITI).

NSCAT—14 GHz (Ku band) scatterometer; resolution of 25 km; two 600-km swaths; used for retrieval of wind speed and direction over the oceans. (provided by NASA).

OCTS—Six visible bands centered on 0.412, 0.443, 0.490, 0.520, 0.565, and 0.670 µm, 20-nm bandwidth, S/N = 450-500; two near-infrared bands centered on 0.765 and 0.865 µm, 40-nm bandwidth, S/N = 450-500; four thermal infrared bands centered on 3.7, 8.5, 11.0, and 12.0 µm, 330- to 1,000-nm bandwidth, NEDT 0.15 to 0.20 K at 300 K; 700-m resolution; 1,400-km swath; ±20° along-track tilting; measurement of ocean color and sea-surface temperature (developed by NASDA).

POLDER—Views ±55° (cross- and along-track); 5-km nadir footprint; nine bands in the visible and near-infrared, 0.443 to 0.910 µm with 10- to 20-nm bandwidth; all-polarization measurements in three of the nine bands (provided by CNES).

RIS—0.5-m diameter corner-cube retro-reflector to derive column density of ozone and trace species from laser absorption measurements. A ground station in the Kanto area will transmit and receive laser pulses in the wavelength region from 0.4 to 14 µm (provided by Japan's Environmental Agency).

TOMS—Six wavelength bands in the region from 0.3086-0.360 µm, with 1-nm bandpass; IFOV 92 km at nadir; cross-track scan 108° (37.3° steps); retrieves daily global ozone (provided by NASA).

ADEOS-II

ADEOS II, to be launched in 1999, will be the main Japanese contribution to IEOS since the prior ADEOS mission falls more within the framework of MTPE Phase I than the EOS era (see *Mission to Planet Earth* section of this Handbook). The basic design of ADEOS II underway. It will have orbital specifications similar to those of the ADEOS mission. AMSR and GLI will be the core facility instruments, to be complemented by ILAS-2 and the U.S. SeaWinds (next-generation instruments of those described above—the *SeaWinds* instrument description appears in the section on EOS instruments.)

AMSR—Advanced Microwave Scanning Radiometer designed to observe atmospheric and oceanic water vapor profiles, determine precipitation, water vapor distribution, cloud water, sea surface temperature, sea ice, and sea surface wind speed; employs six frequencies in the 6 to 90 GHz range, with vertical and horizontal polarization, to secure a temperature resolution of 0.2 to 1 K, at 1 K (goal) radiometric accuracy; instrument design employs a 2-m antenna aperture, and is based on MSR (MOS-1) heritage.

GLI—Imaging spectrometer for global monitoring of biological and physical processes ozone in the spectral range from the ultraviolet to the thermal infrared; 35 bands, with a bandwidth of 10 nm to 20 µm and a signal-to-noise ratio of less than 1,000; 1,600-km swath; instantaneous field-of-view of less than 1 km (some bands are 250 m); instrument design based on VTIR (MOS-1) and OCTS (ADEOS) heritage.

ILAS-II—Consists of two channels additional to those on ILAS; and SeaWinds improves on NSCAT by using scan-beam rather than fan-beam technology.

TRMM

Conducted in cooperation with Japan, TRMM is a joint NASA/NASDA mission with the primary objective of measuring precipitation—a crucial driver of the hydrologic cycle and atmospheric dynamics. TRMM will measure the diurnal variation of precipitation in the tropics from a low-inclination orbit using a variety of sensors. The goal of this mission is to obtain a minimum of 3 years of significant climatological observations of rainfall in the tropics. In tandem with cloud models, TRMM observations will provide accurate estimates of vertical distributions of latent heating in the atmosphere.

NASA provides the TRMM spacecraft, a microwave imager (TMI), a visible/infrared imager (VIRS), a Lightning Imaging Sensor (LIS), a radiation budget instrument (CERES), and instrument integration. Japan provides a precipitation radar (PR) and the H-II rocket to launch the satellite in 1997. TRMM will have a 350-km, 35° orbit. The PR is an electronically scanning radar operating at 13.8 GHz; 4.3 km^2 instantaneous field-of-view at nadir; 220-km swath; the TMI is a five-channel passive microwave imager making measurements from 10 to 91 GHz; and VIRS is a five-channel imaging radiometer (0.63, 1.6, 3.75, 10.7, and 12.0 μm) with nominal 2-km resolution at nadir and 1,500-km swath; similar in design to NOAA's AVHRR-3.

European Earth Observing Satellites

The European Earth observing satellites will make comprehensive research and operational observations of the Earth. There will be two spacecraft series—one for environmental monitoring and atmospheric chemistry (ENVISAT), and one for operational meteorological and climate monitoring (METOP). METOP will contribute significantly to operational meteorology by providing a long-term venue for the operational package in the morning orbit. Both satellites will use the Columbus polar platform, and both will be equipped to work with the European Data Relay Satellite System (DRSS). A major effort is being made on ground-segment development, based on experience gained from ERS-1 and -2. The flight and ground segments are being developed through the participation of ESA, EUMETSAT, and the European Community (EC); cooperation with the U.S. and Japan is also being pursued through exchange of instrumentation and data. In the outyears of the program, advanced instrumentation will be integrated onto the platforms, with candidates including a lidar, a multifrequency SAR, and a high-resolution thermal infrared radiometer.

European Environmental Satellite (ENVISAT)

ENVISAT, provided by ESA, has the dual objectives of continuing ERS measurements and contributing to environmental studies of land surface properties, atmospheric chemistry, aerosol distribution, and marine biology. The instrument package will consist of five ESA-funded instruments and four instruments provided by individual ESA member states. The ESA facility instruments include ASAR, GOMOS, MERIS, MIPAS, and RA-2, which includes a microwave sounder. The following national contributions are also included on the ENVISAT manifest: AATSR, PRAREE, SCARAB, and SCIAMACHY. The first ENVISAT launch is scheduled for 1998.

ASAR—A high-resolution, all-weather imaging SAR that will provide information on ocean waves, surface topography, land surface properties, snow and ice extent, and sea ice extent and motion; operates in two modes (imaging mode and wave mode). The imaging mode takes measurements in the C-band (5.3 GHz), with a bandwidth of 15.55 MHz, 30-m spatial resolution, and 100-km swath width; the wave mode operates at 5.3 GHz and has a spatial resolution of 30 m, generating 5 × 5 km images of the surface at regular intervals to determine ocean wave features.

GOMOS—Monitors global ozone, enhancing knowledge of ozone depletion and its impact on the greenhouse effect; provides stable reference data on global ozone, plus observations of H_2O, NO_2, NO_3, ClO, BrO, OClO, temperature (O_2), and aerosols through the use of two bore-sighted telescopes, each with its own grating spectrometer (spectrometer A covers the spectral ranges of 0.25-0.45 μm and 0.425-0.65 μm [0.6-nm resolution]; spectrometer B covers the ranges of 0.758-0.772 μm and 0.926-0.943 μm [0.07-nm resolution]); limb-viewing mode operates over a vertical range of approximately 20-100 km and has a vertical resolution of ~2 km; synergistic with MIPAS and SCIAMACHY.

MERIS—Measures ocean color and biological components of the ocean, lending insight into the ocean's contribution to the carbon cycle; provides high-spectral-resolution (5-20 nm) measurements in up to 15 selectable channels from 0.405 to 1.030 μm (channel selection programmable in orbit); channels are composites of solar spectrum measured over adjacent Charge Coupled Device (CCD) detectors; ~600 CCD detectors available in the spectral dimension, and up to about one-third of these can be sampled; 1,500-km swath width; spatial resolution programmable to 250 × 250 m and 1,000 × 1,000 m (±20° along-track tilt); synergistic with RA-2, ASCAT, and AATSR.

MIPAS—Limb sounder to measure the composition, dynamics, and radiation balance of the middle and upper atmosphere, i.e., atmospheric chemistry, ozone mapping, and monitoring of the greenhouse effect/global warming; height range of 8-100 km, and 3-km vertical/30-km horizontal resolution; very high spectral resolution (0.025 nm), rapid-scanning capability permits retrieval of temperature, water vapor, ozone, and numerous trace gases, e.g., CH_4, CCl_4, HNO_3; sensitivity ranges from 4.15 to 14.6 μm in four spectral bands; synergistic with GOMOS and SCIAMACHY for complementary measurements, i.e., three-dimensional temperature field, aerosol loading, polar stratospheric cloud detection, and atmospheric chemistry.

RA-2—Provides significant wave height and sea level determination, ocean circulation (dynamics), ice sheet topography, and land mapping data; adaptive pulse-limited radar altimeter possesses a transmit center frequency of 13.8 GHz, and an optional 3.2 GHz transmit frequency to measure and correct for ionospheric delays; an adaptive range window resolution (with bandwidth up to 330 MHz) is used for automatic gain control; synergistic with ASCAT, MERIS, and AATSR; ensures continuity of ERS-1/2 data products.

AATSR—Provides high-precision sea-surface temperature retrieval and land-surface bi-directional measurements for ocean dynamics and radiation interaction studies; imaging radiometer with 10 channels (bandwidths listed in parentheses) (0.470 μm [20 nm], 0.550 μm [20 nm], 0.670 μm [20 nm], 0.870 μm [20 nm], 1.240 μm [20 nm], 1.610 μm [60 nm], 3.750 μm [400 nm], 4.0 μm [TBD], 10.85 μm [1,000 nm], 12.0 μm [1,000 nm]); signal-to-noise ratio equals 20 for the visible/near-infrared channels, 800 at 270 K for the 12- and 10.85-μm channels, and 227 at 270 K for the 3.75-μm channel; 500-km swath width; 500-m field-of-view (FOV) at nadir for channels up to 1.6 μm and a 1-km FOV for channels beyond 1.6 μm; two viewing angles (nadir and 47° forward from nadir); synergistic with RA-2, ASCAT, and MERIS; provides continuity with ERS-1/2 data products.

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

SCARAB—Provides global measurements of the radiation budget; 4-channel (0.2-4, 0.2-50, 0.5-0.7, and 10.5-12.5 μm) mechanical cross-track scanner that includes broadband, total, and shortwave channels for radiation-budget determinations and narrow-band infrared window and visible channels for improved cloud detection. All four channels will have a 60-km spatial resolution and a field-of-view of 100°.

SCIAMACHY—Measures the total concentration and vertical distribution of atmospheric trace gas species, i.e., H_2O, O_3, CH_4, N_2O, NO, NO_2, NO_3, ClO, SO_2, BrO, OClO, HCHO, CO, CO_2, temperature (O_2 and CO_2 bands), and aerosols in the troposphere and stratosphere; two identical optical paths capable of viewing in limb-scanning (including occultation) or nadir modes, using array detectors and grating spectrometers in the spectral ranges of 0.240-0.295 μm (0.11 nm), 0.290-0.405 μm (0.12 nm), 0.400-0.700 μm (0.15 nm), 0.650-1.050 μm (0.20 nm), 0.940-1.350 μm (0.20 nm), 1.980-2.020 μm (0.08 nm), and 2.250-2.390 μm (0.09 nm); signal-to-noise ratio can be up to 5,000 in the ultraviolet/visible and 500 in the infrared; possesses a vertical resolution of 1 km from 20-100 km in limb-sounding mode (3-km retrievals expected); scans ±40° in nadir-viewing mode; 0.25

× 25 km field-of-view at nadir; synergistic with MIPAS and GOMOS.

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

MIPAS, GOMOS, and SCIAMACHY comprehensively monitor greenhouse gases, thereby studying global warming, ozone depletion, and climatic influence. Together with SCARAB, they provide a tool to characterize both the lower and upper atmosphere, including dynamics, radiative transfer, interactions, and the weather.

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

European Meteorological Operational Satellite (METOP)

This collaborative venture between ESA, NOAA, and EUMETSAT has the current objective of operational meteorology and climate monitoring, and a future objective of operational climatology. A preparatory program for METOP was approved at the November 1992 ESA Ministerial Conference, and the first flight is scheduled for mid-2001. The core operational meteorology payload consists of six instruments: AMSU-A1/2, AVHRR-3, DCS (ARGOS+), HIRS-3, IASI, and MHS. The operational meteorological package also includes MCP, S&R, and SEM. In addition, the following instruments are provided for climatological monitoring: ASCAT, AATSR, GOMI, MIMR, and SCARAB. For METOP-1, NOAA plans to contribute instruments that fly on the POES series, with subsequent METOP flights carrying the advanced IRTS, MTS, and VIRSR instruments. Plans call for a second METOP satellite to be launched in 2005. The following subsections address the discrete elements that make up the current POEM-METOP payload configuration, and anticipated enhancements to be integrated onto follow-on flights.

The Operational Meteorological Package on METOP-1 will replace NOAA's morning satellite series. This instrument package will make operational weather observations on a regular basis. This package is synergistic with all other instruments on the METOP satellite, and will facilitate calibration of other instruments subject to atmospheric interference, e.g., AATSR. Brief descriptions of the instruments in the operational meteorological package follow:

AMSU-A1/2—15 channels (23-90 GHz) to measure temperature profiles from ground level to 45 km, with 45-km nadir resolution (14-bit resolution); scan line time of 8 sec includes full aperture calibration.

AVHRR-3—Six spectral channels (five full-time) at 0.58-0.68 µm, 0.72-1.0 µm, 1.58-1.64 µm (sun-side readout)/3.55-3.93 µm (dark-side readout), 10.3-11.3 µm, and 11.5-12.5 µm, with an image resolution of 1-4 km (effective 11-bit resolution); infrared calibration capability, but no visible calibration.

DCS (ARGOS+)—Relays messages from data collection platforms at 401.0 and 136.77 MHz; receives platform and buoy transmissions on 401.65 MHz; monitors over 4,000 platforms worldwide; outputs data via VHF link and stores them on tape.

HIRS-3—20 channels at 0.2-15 µm to cover the surface to the troposphere, with 21-km nadir resolution (12-bit resolution), a scan line time of 6.4 sec, and full aperture calibration.

IASI—Provides atmospheric temperature and humidity profiles with high vertical resolution and accuracy, and continuous monitoring of global radiation, dynamics, and energy flux; high-resolution spectrometer with a spectral band of 3.4-15.5 µm and a spectral resolution of 0.25 cm^{-1}; 1-km vertical resolution; 1 K temperature accuracy.

MCP—Provides direct data handling and broadcast of operational instrument data streams to ground stations.

MHS—Measures precipitation and water vapor profiles with two channels at 89 and 150 GHz, and three at 183.31 GHz (±1, 3, and 7 GHz); scan line time will be 8/3 sec; possesses full-aperture calibration and 15-km nadir resolution (14-bit resolution).

S&R—Receives beacon signals at 121.5, 243, and 406.05 MHz (-154 dBm signal detection level); transmits in real-time at 1,544.5 MHz to ground stations around the world.

SEM—Monitors particles and fields.

METOP-2

The next-generation meteorological operational instruments slated for flight on METOP-2 and subsequent spacecraft include:

IRTS—Scanning radiometer to provide global atmospheric temperature profiles, atmospheric water content, cloud properties, and Earth radiation budget data; 20 channels covering the ground to the troposphere, from 0.2 to 15 µm; 2,250-km swath width, with 21-km (12-bit) resolution at nadir and full aperture calibration; scan line time of 8 sec includes calibration; instrument design based on HIRS-3 heritage.

MTS—Employs 21 channels covering ground level to 73 km, including upper atmosphere soundings; provides full aperture calibration and 45-km nadir resolution (14-bit resolution); scan line time of 8 sec includes calibration.

VIRSR—Provides global monitoring of clouds, sea surface temperature, vegetation, and ice; 2,200-km swath width, with 1.1-km (12-bit) resolution at nadir; employs seven full-time spectral channels (0.605-0.625, 0.860-0.880, 1.580-1.640, 3.620-3.830, 8.400-8.700, 10.30-11.30, and 11.50-12.50µm), plus onboard visible and infrared calibration; scan mode reversed from traditional imagers; signal-to-noise ratio on all infrared channels will be 0.1° and 300 K.

Climatological Monitoring Package

The following facility instruments have been proposed for climatological monitoring, with eventual transition to operational climatology:

AATSR—See description in *ENVISAT* subsection.

ASCAT—Measures ocean surface wind speed and direction, and ocean circulation and dynamics; accurate to 2 m/sec (direction to 20°); provides 25 × 25 km resolution; has a double swath (2 × 500 km) capability; operates at 14 GHz; synergistic with RA-2, MERIS, and AATSR for biophysical characterization of the ocean, ocean dynamics, and energy exchange; ensures continuity with ERS-1/2 data products.

GOMI—A grating spectrometer that will retrieve global ozone distributions from both solar radiation backscatter and differential optical absorption spectroscopy; operates over four spectral channels (0.240-0.295, 0.290-0.405, 0.400-0.605, 0.590-0.790 µm) at a moderately high spectral resolution of 0.2-0.4 nm; pixel size on the ground of 40 × 1.7 km, and spatial resolution between 40 × 40 km and 40 × 320 km.

MIMR—See *EOS Instruments* section of this Handbook for a detailed description.

SCARAB—See description in *ENVISAT* subsection.

POES Series

NOAA's primary agency directive is to provide daily global data for operational forecasts and warnings, with very high reliability. NOAA normally has two POES in operation at the same time, one in a morning and one in an afternoon orbit; each is replaced upon failure or significant degradation of one of its primary sensors or subsystems. Over 120 countries depend on the data from the POES direct broadcast.

The present POES system will continue through 2000. The core instruments for the POES missions are AVHRR-3 and HIRS-3—an imager and an infrared sounder, respectively. POES spacecraft are also equipped with the ARGOS data collection system, S&R, and SEM. POES satellites in afternoon orbit, i.e., NOAA-14, L, N/N', also carry SBUV. The stratospheric and microwave pair of sounders now in use, i.e., SSU and MSU, are being upgraded, beginning with NOAA-K; NOAA-K through -N' will employ the AMSU-A1/2 and AMSU-B sounder pair.

The U.S. and Europe have agreed in principle that

Europe will take over responsibility for the morning satellite of the POES global coverage mission in the 2000 time frame. Planning for this cooperative program includes flight of the NOAA/EUMETSAT operational meteorological payload aboard the METOP series. Also, EUMETSAT will establish a high-latitude European ground station to read out data from both the European and U.S. (NOAA) satellites. Full exchange of data, in a timely manner consistent with operational objectives, will be conducted between NOAA and EUMETSAT. Current plans are for these two agencies to provide morning (EUMETSAT) and afternoon (NOAA) polar satellite global coverage, with each using the same basic instrument complements. The U.S. will provide the AMSU-A1/2, AVHRR-3, HIRS-3, and SEM instruments to be flown on METOP-1; EUMETSAT will provide the AMSU-B instruments for NOAA's POES series; France will provide the ARGOS systems for both the NOAA and EUMETSAT missions; and Canada and France will jointly provide the S&R systems for both NOAA and European polar missions. Each meteorological agency may add other instruments suitable to its particular orbit time and needs.

Direct broadcast of POES data will continue, with European polar satellites also providing direct data broadcast services. In addition, data from potential operational instruments on the EOS satellites will be accessed and disseminated by NOAA.

The establishment and use of a high-latitude European ground station under the cooperative NOAA-EUMETSAT agreement will eliminate blind orbits in coverage by polar-orbiting meteorological satellites. This enhanced ground network will eliminate orbits wherein the satellite fails to pass within line-of-sight for data transmission to its ground station. Both NOAA and EUMETSAT's meteorological payloads will be able to downlink a full orbit's worth of data at full resolution each orbit. As such, there will no longer be a need for low-resolution GAC data to conserve POES onboard data storage capacity. All POES data in the cooperative program will be full-resolution Local Area Coverage (LAC) data. The low-resolution, analog Automatic Picture Transmission (APT) as well as the Direct Sounding Broadcast (DSB) of the current NOAA system will be replaced with Low-Resolution Picture Transmission (LRPT) broadcasts. The High-Resolution Picture Transmission (HRPT) data rate will be changed from 667 kbps to 3.5 Mbps, and the HRPT frequency will be changed to 1,704.5 MHz.

NOAA-K/L/M/N/N' Instruments

ARGOS—Relays messages from data collection platforms at 401.0 and 136.77 MHz; receives platform and buoy transmissions on 401.65 MHz; monitors over 4,000 platforms worldwide; outputs data via VHF link and stores them on tape.

AMSU-A1/2—15 channels (23-90 GHz) to measure temperature profiles from ground level to 45 km, with 45-km nadir resolution (14-bit resolution); scan line time of 8 sec includes full aperture calibration.

AVHRR-3—Six spectral channels (five full-time) at 0.58-0.68 µm, 0.72-1.0 µm, 1.58-1.64 µm (sun-side readout)/3.55-3.93 µm (dark-side readout), 10.3-11.3 µm, and 11.5-12.5 µm, with an image resolution of 1-4 km (effective 11-bit resolution); infrared calibration capability, but no visible calibration.

AMSU-B—Measures precipitation and water vapor profiles with two channels at 89 and 157 GHz, and three at 183.31 GHz (±1, 3, and 7 GHz); scan line time is 8/3 sec; 15-km nadir resolution (14-bit resolution) and full-aperture calibration capability.

HIRS-3—20 channels at 0.2-15 µm to cover the ground to the troposphere, with 21-km nadir resolution (12-bit resolution), a scan line time of 6.4 sec, and full aperture calibration.

SBUV-2 *(NOAA-K/M/N' only)*—12 spectral channels to measure from 0.252-0.322 µm, with a 1-nm bandpass; 256-sec spectral scan; 11.33° × 11.33° instantaneous field-of-view; 14-bit resolution; diffuser plate calibration accomplished with an onboard spectral reflectance/transmittance measurement system; operates only on the day side of the orbit, and performs spectral calibration on the night side.

S&R—Receives beacon signals at 121.5, 243, and 406.05 MHz (-154 dBm signal detection level); transmits in real-time at 1,544.5 MHz to ground stations around the world.

SEM—Monitors particles and fields to measure and predict solar events.

MHS—5-channel, self-calibrating microwave scanning radiometer. The channels in the frequency range 89 to 183 GHz provide a humidity profiling capability.

Landsat-7

Landsat-7 is the latest in a series of satellites that have provided a continuous set of calibrated Earth science data to both national and international users since the early 1970s (see Figure 9). Scientists are using Landsat satellites to gather remotely sensed images of the land surface and surrounding coastal regions for global change research, regional environmental change studies, national security uses and other civil and commercial purposes. Landsat-7, as part of NASA's Mission to Planet Earth, will provide essential land remote-sensing data critical to understanding environmental change and will support a broad range of other important Earth science and Earth resource applications. Landsat produced the first composite multi-spectral mosaic of the 48 contiguous United States. It has been used to monitor deforestation in the Brazilian Amazon and U.S. Pacific Northwest, to determine soil moisture and snow water equivalence and to measure forest cover at the state level. In addition, Landsat has been used to monitor strip mining reclamation, population changes in and around metropolitan areas, and to measure water quality in lakes.

Landsat-7 Program Objectives

- Maintain Landsat data continuity by providing data that are consistent in terms of data acquisition, geometry, spatial resolution, calibration, coverage characteristics, and spectral characteristics with previous Landsat data.

- Generate and periodically refresh a global archive of substantially cloud-free sun-lit land mass imagery.

- Continue to make Landsat-type data available to U.S. and international user at the cost of fulfilling users requests and expand the use of such data for global change research and commercial purposes.

Landsat Chronology

The first Landsat, originally called ERTS-1 for Earth Resources Technology Satellite, was developed and launched by NASA in July 1972. Subsequent Landsat launches occurred in January of 1975 and March 1978. In the mean time, a second generation of Landsat satellites was developed. Landsat-4 was launched in July of 1982 and Landsat-5 in March of 1984. Landsat images are still being received from Landsat-5. As a result, there is available a continuous set of Landsat images from mid-1972 until the present.

Landsat-7 was authorized by a Presidential Directive signed by President Bush, establishing a joint NASA/Air Force program. Following the failure of Landsat-6 and the withdrawal of the DoD from the program, a second Presidential Decision Directive signed by President Clinton established a joint program, with NASA, NOAA, and the USGS sharing responsibilities for the Landsat-7 Program. NASA is responsible for the development and launch of the satellite and the development of the ground system; NOAA is responsible for operating the satellite and distribution of the data; and the USGS is responsible for maintaining an archive of Landsat and other remotely sensed data.

Landsat-7 Flight Segment

Landsat-7 will be launched in 1998 from the Western Test Range by a Delta-II Expendable Launch Vehicle. The Landsat-7 satellite consists of a spacecraft bus and a single instrument, the Enhanced Thematic Mapper Plus (ETM+). (See the *EOS Instruments* section of this Handbook.)

A Landsat World Wide Reference System has catalogued the world's land mass into 57,784 scenes, each 185 km wide by 170 km long. The orbit altitude will be approximately 705 km with a sun-synchronous 98° inclination and a descending equatorial crossing time of 10:00 a.m. The orbit will be adjusted upon reaching orbit so that its 16-day repeat cycle coincides with the Landsat World Wide Reference System.

A state-of-the-art solid state recorder capable of storing 380 gigabits of data (100 scenes) will be used to store selected scenes from around the world for playback over a U.S. ground station. In addition to stored data, real-time data from the ETM+ can be transmitted to cooperating international ground stations or to the U.S. ground station.

Landsat-7 Ground Segment

A ground system that includes a spacecraft control center and a data processing facility are being developed by the Goddard Space Flight Center in Greenbelt, MD. These Landsat-unique facilities, augmented by existing NASA and NOAA institutional facilities, will be utilized to communicate with Landsat, control all spacecraft and instrument operations, and process received data. After launch and on-orbit activation of the satellite, Landsat-unique portions of the ground system will be turned over to NOAA for operation. Flight operations will be controlled by the control center at NASA/GSFC with commands uplinked via NOAA Command and Data Acquisition facilities or NASA TDRSS. Scientific data will be downlinked, processed, and distributed for NOAA by the United States Geological Survey's EROS Data Center (EDC) in Sioux Falls, South Dakota.

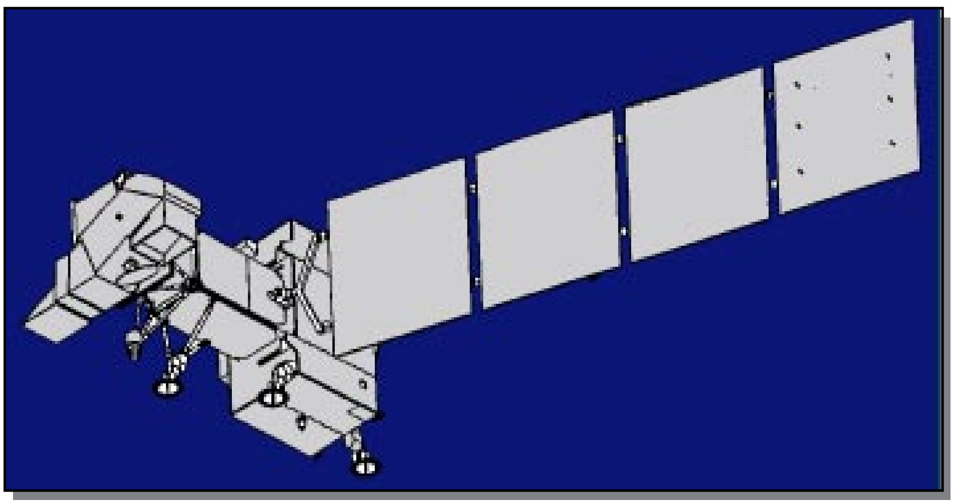


Figure 9. **Landsat-7**

The ground system at EDC will be capable of capturing and processing 250 Landsat scenes per day and delivering at least 100 of the scenes to users each day. Data captured will routinely be available for user ordering within 24 hours after it has been received on the ground. The data will contain sufficient information to allow a user to radiometrically correct the data to within 5 percent and to geometrically locate the scene on the Earth to within 250 m. The user will be able to query metadata and image browse data to determine if it contains suitable information. If so, the data can be ordered and delivered either electronically or in a digital format by common carrier.

Landsat Calibration and Validation

Calibration is essential to the role of Landsat-7 in the EOS era. The ETM+ aboard Landsat-7 must be accurately calibrated in order to use its data in concert with the data from the other satellites and thereby realize the full potential of the integrated remote sensing systems under development by the MTPE Office.

The inclusion of a new full-aperture solar calibrator and a partial-aperture solar calibrator on Landsat-7 will afford improved ETM+ calibrations relative to the earlier Thematic Mapper (TM) and Multi-Spectral Scanner (MSS) sensors on Landsats-4 and -5. These two devices will permit use of the sun, with its known exo-atmospheric irradiance, as an absolute radiometric calibration source. The data provided by the on-board solar calibrators, in conjunction with an internal calibration lamp and occasional ground-based validation experiments, will permit calibration to an uncertainty better than 5 percent. This level of accuracy is consistent with the radiometric requirements for the EOS sensors.

EOS Instruments

ACRIM
AIRS/AMSU/MHS
ASTER
CERES
DORIS/SSALT/AMR
EOS Color
EOSP
ETM+
GLAS
HIRDLS
LIS
MIMR
MISR
MLS
MODIS
MOPITT
ODUS
SAGE III
SeaWinds
SOLSTICE
TES

EOS Instruments

The EOS facility instruments were major instruments defined in the Announcement of Opportunity (AO) for EOS as being developed and managed by various NASA Centers. The Centers were to take charge of the engineering aspects and costs involved in the development of the instruments. The AO invited proposals by scientists who wanted to serve as Team Leader or Team Member of science teams that would provide oversight and guidance to the development of the facility instruments. The science teams would be the source of the algorithms that would lead to the products for each facility instrument. They would also support instrument calibration and verification activities.

U.S. facility instruments that are now part of the EOS Program are AIRS (JPL), MODIS (GSFC), and GLAS (GSFC). In addition to the U.S. facility instruments, the Japanese partners in Mission to Planet Earth have correspondingly provided the ASTER facility instrument (Japanese Ministry of International Trade and Industry, MITI) and ODUS (National Space Development Agency, NASDA), and the European Space Agency (ESA) is providing the MIMR instrument, which has a joint ESA/NASA-funded science team. The French Centre Nationale d'Etudes Spatiales (CNES) is providing the radar altimetry instrument, SSALT.

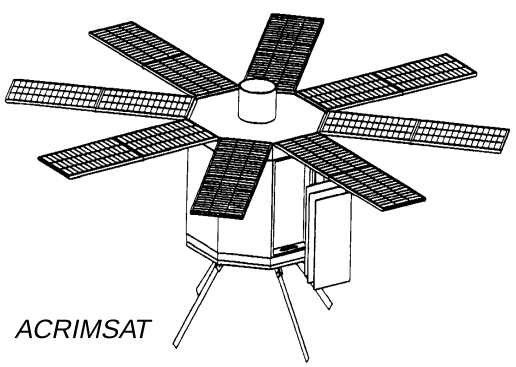
The EOS PI instruments were understood to be instruments that would be the responsibility of the proposer and his institution to develop and manage. The selected proposers became the Principal Investigators for their own instruments and assembled their own teams of co-investigators to provide the algorithms for the products. The PI's institution took responsibility for the engineering and cost aspects of the instrument's development.

EOS Instrument Teams help define the scientific requirements for their respective instruments, and generate the algorithms that will be used to process the data into useful data products. For in-depth presentation of these algorithms, see the Algorithm Theoretical Basis Documents [ATBDs] page on the World Wide Web. Each ATBD table of contents may be viewed, and PostScript copies may be downloaded for printing, or the entire document can be viewed using a PDF reader such as Adobe Acrobat, by accessing the following location:

http://spso.gsfc.nasa.gov/atbd/pg1.html

ACRIM

Active Cavity Radiometer Irradiance Monitor



Key ACRIM Facts

- Selected for flight of opportunity
- Heritage: ACRIM II (UARS)
- Three Total Irradiance Detectors: One to monitor solar irradiance, two to calibrate optical degradation of the first
- Monitors the variability of total solar irradiance
- Solar irradiance uncertainty of 0.1%; long-term precision of 5 ppm per year
- Sampling interval ~2 minutes
- Sensor assembly mated to small-satellite system to make dedicated ACRIMSAT free-flying satellite
- ACRIMSAT is a joint Jet Propulsion Laboratory (JPL)/Industrial Partner effort.

JPL provides:

ACRIM sensor assembly, calibration and testing, backup data downlink, as well as science, data processing, and archiving.

Industrial Partner provides:

Satellite subsystems, integration of sensor assembly, integration of payload and launch (piggy back on Pegasus), and satellite operations, station keeping and data downlink.

The science objectives of the ACRIMSAT Mission are in the fields of climatology and solar physics. Sustained changes in the total solar irradiance (TSI) of as little as a few tenths of one percent per century could be primary causal factors for significant climate change on time scales ranging from decades to centuries. It is clear from paleoclimate research that periodic solar-irradiance-driven climate changes have occurred. There is compelling evidence that some of these may have been driven by intrinsic solar variability. A precise, long-term record of solar luminosity variation is required to provide empirical evidence of the sun's role in climate change and to separate its effect from other climate drivers. The same record, together with other solar observations, will yield an improved understanding of the physics of the sun, the causes of luminosity variations, and could eventually lead to a predictive capability for solar-driven climate change.

The National Research Council recently published its findings regarding research priorities for Solar Influences on Global Change, one of the seven science elements of the U.S. Global Change Research Program. Their recommendations include "monitoring total and spectral solar irradiance from an uninterrupted, overlapping series of spacecraft radiometers employing in-flight sensitivity tracking" as this element's highest priority and most urgent activity. The EOS/ACRIMSAT mission is designed to be a cost-effective, small-satellite approach to meeting that priority.

The sun is a variable star. Its luminosity has been found to vary by 0.1 percent over a solar cycle in phase with the level of solar magnetic activity. Photometric observations of many solar-type stars have revealed that brightness variations correlated with magnetic activity like the sun's are a common phenomenon. Many demonstrate higher variability than the sun, leading to speculation that the sun's variability may have been greater in the past and may be greater again in the future. This would have significant implications for climate change.

A precision TSI database with resolution adequate to relate centuries of systematic TSI variation to climate change must be compiled from the results of many flight experiments. With a nominal lifetime of 5 years per experiment, their contiguous results must be related with the maximum precision accessible to current technology, on the order of 10 ppm. This far exceeds the capability of current "ambient temperature" flight instrumentation to define the "absolute uncertainty" of the TSI (>1000 ppm) and even that of cryogenic instrumentation currently under development (>100 ppm). The uncertainty of modeling TSI using ground-based observations of proxy solar emission features is orders of magnitude less precise.

The approach capable of providing the maximum precision for the long-term TSI database with current measurement technology employs an "overlap strategy" in which successive ambient temperature TSI satellite experiments are compared in flight, transferring their operational precision to the database. The current generation of ambient temperature ACRIM flight instrumentation has demonstrated a capability of providing annual precision smaller than 5 ppm of the TSI.

The EOS/ACRIM experiment was selected to provide the TSI database during the EOS mission. We propose to accomplish the ACRIM science objectives using a cost-effective ACRIMSAT small-satellite submission to implement an overlap measurement strategy and provide the EOS mission segment of the long-term, precision, climate TSI database.

ACRIMSAT uses the Active Cavity Radiometer Irradiance Monitor technology flown successfully on NASA's Solar Maximum Mission, Upper Atmosphere Research Satellite, Spacelab 1, and ATLAS missions. A down-sized version of ACRIM instrumentation will be mated with small-satellite technology to construct dedicated ACRIMSAT satellites. ACRIMSATs with a launch volume of less than 0.25 m^3, can be launched two at a time "piggy back" on Pegasus boosters, reducing launch costs to a minimum. The first two ACRIMSATs can be on orbit within 24 months of mission startup, enhancing the possibility of implementing the overlap strategy with the Upper Atmosphere Research Satellite ACRIM II

ACRIM Parameters

All information applies to the complete satellite

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

Swath: n/a (looks at sun)

Spatial resolution: n/a (looks at sun)

Mass: 15 kg

Duty cycle: 40 minutes on sun each orbit

Power: 25 W (average)

Data rate: 1 kbps

Thermal control by: Host spacecraft and instrument heater

Thermal operating range: 10-30°C

FOV: ±2.5°

Pointing requirements (platform+instrument, 3σ):
Control: 360 arcsec/axis
Knowledge: 180 arcsec/axis
Stability: 360 arcsec/axis
Jitter: 360 arcsec/axis

Physical size:
Satellite body: Octagon 20 cm across (flat-to-flat), 12.7 cm deep
Solar Panels: (8) 45.7 cm (tip-to-tip)

Requires pointing platform to be provided by spacecraft

Solar Pointing: Spin stabilization about axis of symmetry experiment during its extended mission and the SOHO/VIRGO experiment prior to the end of its two-year minimum mission. A series of ACRIMSATs is proposed that could provide overlapping satellite total solar irradiance observations throughout the EOS mission.

Principal Investigator Richard C. Willson

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

For Further Information

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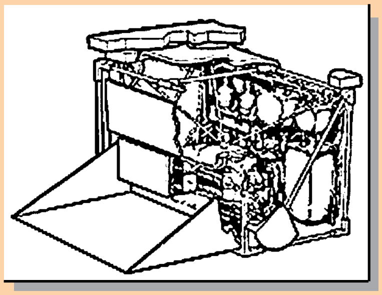
ACRIM Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Level-1A Product	0.1% :: 0.0005%	2 minutes		N/A :: Top of Atmosphere

AIRS • AMSU • MHS

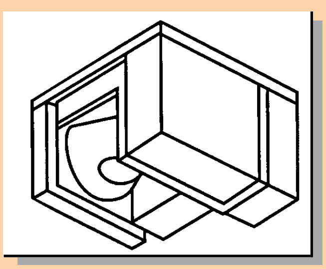
Atmospheric Infrared Sounder



Key AIRS Facts

- Selected for flight on EOS PM series
- Heritage: AMTS study
- Measures the Earth's outgoing radiation 0.4 to 1.0 µm and 3.7 to 15.4 µm
- Phase C/D start March 1991
- Prime Contractor: LORAL
- Responsible Center: Jet Propulsion Laboratory

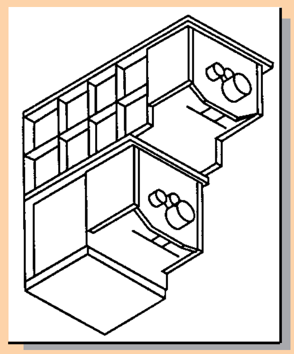
Microwave Humidity Sounder



Key MHS Facts

- Selected for flight on EOS PM Series
- Heritage: MSU
- Microwave radiometer
- Provides atmospheric water vapor profile measurements
- Phase C/D start expected June 1995
- Prime Contractor: Matra Marconi

Advanced Microwave Sounding Unit



Key AMSU Facts

- Selected for flight on EOS PM Series
- Heritage: MSU
- Microwave radiometer
- Provides atmospheric temperature measurements from the surface up to 40 km
- Onboard NOAA-K/L/M
- Phase C/D start December 1992
- Prime Contractor: Aerojet General Corporation
- Responsible Center: NASA/Goddard Space Flight Center

AIRS has been selected to fly on the EOS PM-1 satellite with two operational microwave sounders: AMSU and MHS. AIRS, AMSU, and MHS measurements will be analyzed jointly to filter out the effects of clouds from the IR data in order to derive clear-column air temperature profiles and surface temperatures with high vertical resolution and accuracy. Together, these instruments constitute the advanced operational sounding system, relative to the High-Resolution Infrared Sounder/Microwave Sounding Unit (HIRS/MSU) system that currently operates on NOAA satellites.

The data retrieved from the AIRS/AMSU/MHS instrument complement will improve global modeling efforts, numerical weather prediction, study of the global energy and water cycles, detection of the effects of greenhouse gases, investigation of atmosphere-surface interactions, and monitoring of climate variations and trends. These objectives will be met through improvements in the accuracy of several weather and climate parameters, including atmospheric temperature and water vapor, land and ocean surface temperature, cloud distribution and spectral properties, and outgoing longwave radiation. Simultaneous observations of the atmosphere and clouds from AIRS will allow characterization of the spectral properties of clouds for enhanced understanding of their role in modulating the greenhouse effect, and the increased resolution and number of infrared sounding channels (an increase of two orders of magnitude beyond current operational sounders) will improve the accuracy of weather forecasting.

AIRS, AMSU, and MHS together constitute a single facility instrument program, so AIRS products are often the result of joint operations. Standard and research data products for the complement are delineated below:

Standard Products

- For the atmosphere, AIRS/AMSU will provide a temperature profile, humidity profile, total precipitable water, fractional cloud cover, cloud-top height, and cloud-top temperature.
- For the land, AIRS/AMSU will provide skin surface temperature, plus day and night land surface temperature difference. AIRS will provide outgoing day/night longwave surface flux.
- For the ocean, AIRS/AMSU will provide skin surface temperature. AIRS will provide outgoing day/night longwave surface flux.

Research Products

- For the atmosphere, AIRS/AMSU/MHS will provide a precipitation estimate, and tropopause and stratopause height. AIRS will provide outgoing longwave spectral radiation and cloud optical thickness. AMSU will provide cloud thermodynamic phase (ice/water) and cloud water content.
- For the land, AIRS/AMSU will provide surface spectral emissivity, surface albedo, and net shortwave flux.
- For the ocean, AIRS will provide net shortwave flux. AMSU will provide sea-ice cover (old/new) and surface (scalar) wind speed.

Standard products are distinguished from research products in that the latter will require post-launch verification.

AIRS

AIRS is designed to meet the NOAA requirement of a high-resolution infrared (IR) sounder to fly on future operational weather satellites.

AIRS is a high-resolution sounder covering the spectral range between 0.4 and 15.4 µm, measuring simultaneously in over 2,300 spectral channels. The spectral resolution ($\lambda/\Delta\lambda$) is 1,200. The high spectral resolution enables the separation of the contribution of unwanted spectral emissions and, in particular, provides spectrally clean “super windows,” which are ideal for surface observations. All channels will be downlinked on a routine operational basis.

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

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

Cloud-top heights and effective cloud amount are determined, based on the calculated atmospheric temperature, humidity, and surface temperature, combined with the calculated clear-column radiance and measured radiance. The spectral dependence of the opacity of the clouds will distinguish various cloud types (including cirrus clouds). Ozone retrieval is performed simultaneously with the other parameters using the 9.6-µm ozone band.

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

AIRS Parameters

High spectral resolution, multispectral infrared sounder

Operates with AMSU for all-weather capability

1 K temperature retrieval accuracy

0.05 emissivity accuracy

Array grating spectrometer (3.74 to 15.4 µm), with a spectral resolution of 1,200 ($\lambda/\Delta\lambda$)

Swath: 1,650 km

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

Mass: 156 kg

Duty cycle: 100%

Power: 256 W

Data rate: 1.44 Mbps

Thermal control by: Redundant 60 K Stirling cycle coolers, heater, mini thermal bus, two-stage radiator

Thermal operating range: 20-25° C

FOV: ±49.5° cross-track

Instrument IFOV: 1.1° circular

Pointing requirements (platform+instrument, 3σ):
Control: 360 arcsec
Knowledge: 180 arcsec
Stability: 360/60 sec
Jitter: TBD

Physical size: 139.7 × 77.5 × 76.2 cm (stowed); 139.7 × 151.2 × 76.2 cm (deployed) of their role in modulating the greenhouse effect, and the increased resolution and number of infrared sounding channels (an increase of two orders of magnitude beyond current operational sounders) will improve the accuracy of weather forecasting.

AMSU and MHS

AMSU is designed primarily to obtain profiles of stratospheric temperature and to provide a cloud-filtering capability for tropospheric observations; MHS is designed to obtain profiles of atmospheric humidity and to detect precipitation under clouds with 15-km (nadir) resolution. AMSU and MHS have a total of 20 channels: 15 are assigned to AMSU, each having a 3.3° beamwidth, and five are assigned to MHS, each having a 1.1° beamwidth. Channels 3 to 14 on AMSU are situated on the low-frequency side of the oxygen resonance band (50-60 GHz) and are used for temperature sounding. Successive channels in this band are situated at frequencies with increasing opacity, therefore responding to radiation from increasing altitudes. Channel 1 [located on the first (weak) water vapor resonance line] is used to obtain estimates of total column water vapor in the atmosphere. Channel 2 (at 31 GHz) is used to indicate the presence of rain.

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

AMSU Parameters

Passive microwave radiometer that measures atmospheric temperature

Swath: 1,650 km

Spatial resolution: 40 km horizontal at nadir

Mass: 100 kg

Duty cycle: 100%

Power: 125 W

Data rate: 3.2 kbps

Thermal control by: Heater, central thermal bus, radiator

Thermal operating range: 0-20° C

FOV: ±49.5°

Instrument IFOV: 3.3°

Pointing requirements (platform+instrument, 3σ):
Control: 720 arcsec
Knowledge: 360 arcsec
Stability: 360 arcsec/sec
Jitter: 360 arcsec/sec

Physical size: 65.5 × 29.9 × 59.2 cm (A1); 54.6 × 64.9 × 69.7 cm (A2)

Team Leader
Moustafa Chahine

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

For 20 years, Dr. Chahine has been directly involved in remote-sensing theory and experiments. His resume reflects roles as Principal Investigator, designer and developer, and analyst in remote sensing experiments. He developed the Physical Relaxation Method for retrieving atmospheric profiles from radiance observations. Subsequently, he formulated a multispectral approach using infrared and microwave data for remote sensing in the presence of clouds. These data analysis techniques were successfully applied in 1980 to produce the first global distribution of the Earth surface temperature using the HIRS/ MSU sounders data.

Dr. Chahine was integrally involved in the AMTS study, which laid the basis for the current AIRS spectrometer. Dr. Chahine served as a member of the NASA Earth System Sciences Committee (ESSC), which developed the program leading to EOS, and currently is Chairman of the Science Steering Group of a closely related effort, the World Meteorological Organization's Global Energy and Water Cycle Experiment (GEWEX). Dr. Chahine is a Fellow of the American Physical Society and the British Meteorological Society. In 1969, he was awarded the NASA Medal for Exceptional Scientific Achievements and, in 1984, the NASA Outstanding Leadership Medal.

MHS Parameters

Passive microwave radiometer for humidity profiling, consisting of five channels: 1 at 89 GHz, 1 at 166 GHz, and 3 at 183.3 GHz

Swath: 1,650 km

Spatial resolution: 13.5 km horizontal at nadir

Mass: 66 kg

Duty cycle: 100%

Power: 85 W (average), 190 W (peak)

Data rate: 4.2 kbps

Thermal control by: Radiator

Thermal operating range: 0-40° C

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

Instrument IFOV: 1.1°

Pointing requirements (platform+instrument, 3σ):
Control: 3,600 arcsec
Knowledge: 360 arcsec
Stability: 74 arcsec/sec
Jitter: TBD

Physical size: 77.4 × 99 × 56 cm

Science Team Members

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Joel Susskind
NASA/Goddard Space Flight Center

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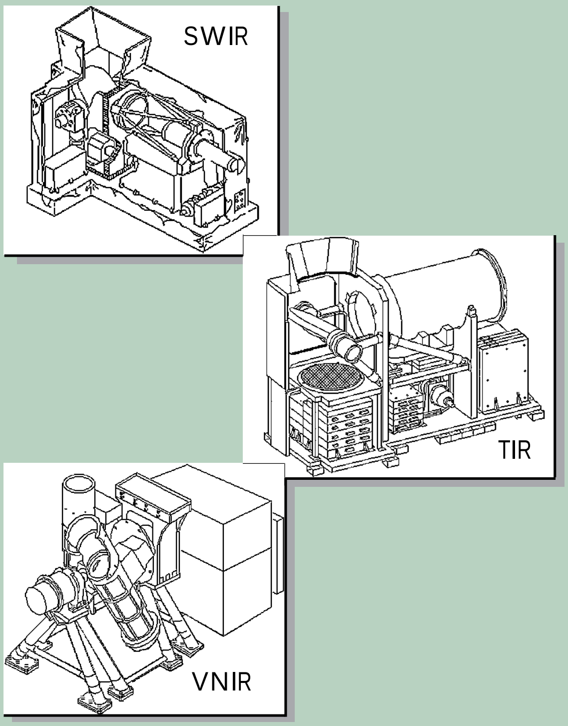
AIRS/AMSU/MHS Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Level-1B Radiance (AIRS)	3% (190-330 K) :: 0.2 K NEdT at 250 K	2 / day (d,n)	15 km :: Global	N / A :: N / A
Cloud Product (AIRS/AMSU/MHS)	TBD	2 / day (d,n)	50 km :: Global	N / A :: Cloud
Humidity Product (AIRS/MHS)	20% Precipitable H_2O :: N / A	2 / day (d,n)	50 km :: Global	2 km :: Surface to 100 mb
Temperature Product (AIRS/AMSU)	Absolute 1 K :: N / A	2 / day (d,n)	50 km :: Land, Ocean	1 km :: Surface to 100 mb
Level-1B Radiance (AMSU)	1.5 K :: 0.5 K	2 / day (d,n)	40 km :: Global	N / A :: N / A
Level-1B Radiance (MHS)	1 K :: 0.6 K	2 / day (d,n)	15 km :: Global	N / A :: N / A

NOTE: These standard data products are preliminary pending peer review and agreement with the responsible EOS investigators

ASTER

Advanced Spaceborne Thermal Emission and Reflection Radiometer



Key ASTER Facts

- Selected for flight on EOS AM-1
- Heritage: MESSR and OPS
- Imaging radiometer
- Provides high-resolution images of the land surface, water, ice, and clouds
- Same-orbit stereo capability
- 14 multispectral bands from visible through thermal infrared
- Not scheduled for further flights other than EOS AM-1
- Japan (MITI) to provide the instrument
- Prime Contractor: NEC (systems integration, VNIR, and Common Signal Processer)
- Subcontractors: MELCO (SWIR and cryocooler), Fujitsu (TIR and cryocooler), and HITACHI (master power supply)

ASTER is a facility instrument provided for the EOS AM-1 platform by the Japanese Ministry of International Trade and Industry (MITI). It will provide high spatial resolution (15- to 90-m) multispectral images of the Earth's surface and clouds in order to better understand the physical processes that affect climate change. While the Moderate-Resolution Imaging Spectroradiometer (MODIS) and Multi-Angle Imaging Spectro-Radiometer (MISR) will monitor many of the same variables globally and on a daily basis, ASTER will provide data at a scale that can be directly related to detailed physical processes. These data will bridge the gap between field observations and data acquired by MODIS and MISR, and between process models and climate and/or forecast models. ASTER data will also be used for long-term monitoring of local and regional changes on the Earth's surface, which either lead to or are in response to global climate change, e.g., land use, deforestation, desertification, lake and playa water level changes, and other changes in vegetation communities, glacial movement, and volcanic processes.

Clouds are one of the most important variables in the global climate system. With its high-spatial-resolution, broad spectral coverage, and stereo capability, ASTER will provide essential measurements of cloud amount, type, spatial distribution, morphology, and radiative properties.

ASTER will provide radiative (brightness) temperature, and the multispectral TIR data can be used to derive surface kinetic temperature and spectral emissivity. Radiative temperature is an element in the surface heat balance. Surface kinetic temperature can be used to determine elements of surface process models, sensible heat flux, latent heat flux, and ground heat conduction. Surface temperatures are also related to thermophysical properties (such as thermal inertia), vegetation health, soil moisture, temporal land classification, e.g., wet vs. dry, vegetated vs. bare soil, and evapotranspiration.

ASTER will operate in three visible and near-infrared (VNIR) channels between 0.5 and 0.9µm, with 15-m resolution; six shortwave infrared (SWIR) channels between 1.6 and 2.43 µm, with 30-m resolution; and five thermal infrared (TIR) channels between 8 and 12 µm, with 90-m resolution. The instrument will acquire data over a 60-km swath whose center is pointable cross-track ±8.55° in the SWIR and TIR, with the VNIR pointable out to ±24°. An additional VNIR telescope (aft pointing) covers the wavelength range of Channel 3. By combining these data with those for Channel 3, stereo views can be created, with a base-to-height ratio of 0.6. ASTER's pointing capabilities will be such that any point on the globe will be accessible at least once every 16 days in all 14 bands and once every 5 days in the three VNIR channels.

ASTER data products will exploit combinations of VNIR, SWIR, and TIR for cloud studies, surface mapping, soil and geologic studies, volcano monitoring, and surface temperature, emissivity, and reflectivity determination. VNIR and SWIR bands will be used for investigation of land use patterns and vegetation, VNIR and TIR combinations for the study of coral reefs and glaciers, and VNIR for digital elevation models (DEMs). TIR channels will be used for study of evapotranspiration, and land and ocean temperature. The stereoscopic capability will yield local surface DEMs and allow observations of local topography, cloud structure, volcanic plumes, and glacial changes.

Team Leaders
Hiroji Tsu

Hiroji Tsu, the ASTER Science Team Leader, received a B.c.,M.S.and Ph.D. from University of Tokyo. He joined the Geological Survey of Japan as a researcher of Geophysics in1970. He moved on to Earth Remote Sensing Data Analysis Center (ERSDAC) in1993,and has been a general manager of R&D Department.

ASTER Parameters

Multispectral imager for reflected and emitted radiation measurements of Earth's surface

4% absolute radiometric accuracy in VNIR and SWIR bands

Absolute temperature accuracy is 3 K in 200-240 K range, 2 K in 240-270 K range, 1 K in 270-340 K range, and 2 K in 340-370 K range for TIR bands

Swath: 60 km at nadir, swath center is pointable cross-track ±106 km for SWIR and TIR, and ±314 km for VNIR

Spatial resolution: VNIR (0.5-0.9 µm), 15 m [stereo (0.7-0.9 µm), 15 m horizontal, 25 m vertical]; SWIR (1.6-2.43 µm), 30 m; TIR (8-12 µm), 90 m

Mass: 421 kg

Duty cycle: 8% (VNIR and SWIR, daylight only), 16% (TIR)

Power: 463 W (average), 646 W (peak)

Data rate: 8.3 Mbps (average), 89.2 Mbps (peak)

Thermal control by: 80 K Stirling cycle coolers, heaters, cold plate/capillary pumped loop, and radiators

Thermal operating range: 10-28° C

FOV *(all pointing is near nadir, except VNIR both nadir and 27.6° backward from nadir)*: VNIR = 6.09° (nadir) × IFOV, 5.19° (backward) × IFOV, SWIR = TIR = 4.9°

Instrument IFOV: VNIR = 21.5 µrad (nadir), 18.6 µrad (backward), SWIR =42.6 µrad (nadir), TIR = 128 µrad (nadir)

Pointing requirements (platform+instrument, 3σ):
Control: 1 km on ground (all axes)
Knowledge: 342 m on ground (per axes)
Stability: 2 pixels per 60 sec (roll = 8.8, pitch = 8.8, yaw - 15 arcsec)
Jitter: 1-2 pixel per 9 sec (roll = 8.8, pitch= 4.4, yaw = 52 arcsec)
(Requirements vary with telescope)

Physical size: VNIR = 57.9 × 65.1× 83.2 cm, SWIR = 72.3 × 134 × 90.6 cm, TIR = 73 × 183 × 110 cm, CSP/VEL (electronics) = 33.4 × 54 × 31.5 cm, MPS (electronics) = 30 × 50 × 32 cm

Team Leaders (cont'd)

Anne B. Kahle

Anne Kahle, the U.S. Science Team Leader, received her B.S. and M.S. in Geophysics from the University of Alaska and her Ph.D. from UCLA in Meteorology. She worked at the RAND Corp. from 1962 as a Senior Physical Scientist and joined JPL in 1974, where she is a Senior Research Scientist.

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For Further Information

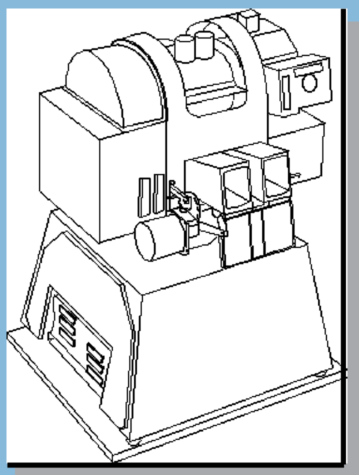
Fujisada, H., and A. Ono, 1991: Overview of ASTER Design Concept, *Future European and Japanese Remote-Sensing Sensors and Programs, 1-2 April 1991, Orlando, Florida—Proceedings of the SPIE - The International Society for Optical Engineering, Vol. 1490*, P. Slater, Ed., Society of Photo-Optical Instrumentation Engineers, Bellingham, Washington, 244-254.

ASTER Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Reconstructed, Unprocessed Instrument Data		1/(16 day)	15, 30, 90 m :: Global	N/A :: Of Sensor
Registered Radiance at Sensor	2-4% :: 1%	1/(16 day)	15, 30, 90 m :: Global	N/A :: Of Sensor
Decorrelation Stretch	N/A :: N/A	1/(16 day)	90 m :: Land/Regional, Local	N/A :: Surface
Brightness Temperature	1-2 K :: 0.3 K	1/(16 day)	90 m :: Global	N/A :: Surface
Surface Reflectance	4% :: 1%	1/(16 day)	15, 30 m :: Land/ Regional, Local	N/A :: Surface
Surface Radiance	2% :: 1%	1/(16 day)	15, 30, 90 m :: Land/ Regional, Local	N/A :: Surface
Surface Emissivity	0.05-0.1 :: 0.005	1/(16 day)	90 m :: Local	N/A :: Surface
Surface Kinetic Temperature	1-4 K :: 1%	1/(16 day)	90 m :: Local	N/A :: Surface
Digital Elevation Model	≥7 m (w/GCPs) :: ≥10 m (no GCPs)	1/(16 day)	15 m :: Land/ Regional, Local	1 m :: Surface

CERES

Clouds and the Earth's Radiant Energy System



Key CERES Facts

- Selected for flight on TRMM, EOS AM, and EOS PM series
- Heritage: ERBE
- Two broadband, scanning radiometers: One cross-track mode, one rotating plane (bi-axial scanning)
- Measures Earth's radiation budget and atmospheric radiation from the top of the atmosphere to the surface
- First instrument (cross-track scanning) will essentially continue the ERBE mission and the second (biaxially scanning) will provide angular flux information that will improve accuracy of angular models used to derive the Earth's radiative balance
- Single scanner on TRMM mission (1997)
- Dual scanners on EOS AM-1 (1998), PM-1 (2000), and single thereafter
- Phase C/D start January 1991
- Prime Contractor: TRW
- Responsible Center: NASA/Langley Research Center

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

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

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

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

Geostationary satellite data will be used to fill in missing times and regions. Improved methods of time-space assimilation and interpolation across data voids will also be used.

Principal Investigator
Bruce Barkstrom

Bruce Barkstrom received a B.S. in Physics from the University of Illinois. He received an M.S. and Ph.D. in Astronomy from Northwestern University. Following a position as Research Associate with the National Center for Atmospheric Research, he had a 5-year teaching assignment with George Washington University.

In 1979, Dr. Barkstrom joined the NASA/Langley Research Center. He serves as the ERBE Experiment Scientist and Science Team Leader. As such, he was directly responsible for the ERBE instrument design and calibration, as well as the ERBE data interpretation. He was also responsible for science project management of the ERBE team of 17 Principal and 40 Co-Investigators.

Co-Investigators

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Thomas P. Charlock
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James A. Coakley
Oregon State University

CERES Parameters

Three channels in each radiometer:
Total radiance (0.3 to >50 µm)
Shortwave (0.3 to 5 µm)
Longwave (8 to 12 µm)

Swath: Limb to limb

Spatial resolution: 21 km at nadir

Mass: 90 kg [two scanners]

Duty cycle: 100%

Power: 103 W (average), 106 W (peak) [two scanners]

Data rate: 20 kbps [two scanners]

Thermal control by: Heaters, radiators

Thermal operating range: -15-35° C (electronics), 37-39° C (detectors)

FOV: ±78° cross-track, 360° azimuth

Instrument IFOV: 14 mrad

Pointing requirements (platform+instrument, 3σ):
Control: 720 arcsec
Knowledge: 180 arcsec
Stability: 79 arcsec/6.6 sec

Physical size: 60 × 60 × 57.6 cm/unit (stowed), 60 × 60 × 70 cm/unit (deployed)

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For Further Information

Barkstrom, B.R., (Ed.),1990: *Long-Term Monitoring of the Earth's Radiation Budget, 17-18 April 1990, Orlando, Florida—Proceedings of the SPIE - The International Society for Optical Engineering, Vol. 1299.* Society of Photo-Optical Instrumentation Engineers, Bellingham, Washington, 265 pp.

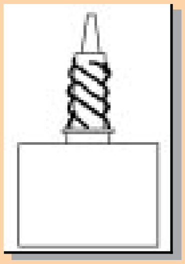
CERES Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Instantaneous Instrument Scans (BDS)	1-2% :: 0.005	4 hour :: 1 day	25 km :: Global	N/A :: Top of Atmosphere
Instantaneous Top of Atmosphere Fluxes (ES8)	15 W/m**2 LW; 40 W/m**2 SW	4 hour :: 1 day	25 km :: Global	N/A :: Top of Atmosphere
*Regionally Averaged Top of Atmosphere Fluxes (ES9)**	10 W/m**2 LW; 15 W/m**2 SW	4 hour :: 1 month	2.5 x 2.5 deg Region :: Global	N/A :: Top of Atmosphere
*Regionally and Monthly Averaged Top of Atmosphere Fluxes (ES4)**	3 W/m**2 LW; 5 W/m**2 SW	N/A :: 1 month	2.5 x 2.5 deg Region :: Global	N/A :: Top of Atmosphere
*Monthly and Regionally Averaged Top of Atmosphere Fluxes (ES4G)**	3 W/m**2 LW; 5 W/m**2 SW	N/A :: 1 month	2.5 x 2.5 deg Region :: Global	N/A :: Top of Atmosphere
Single Satellite Footprint Top of Atmosphere and Surface Fluxes and Clouds (SSF)	5 W/m**2 LW; 15 W/m**2 SW; depends on cloud parameters	N/A :: 1 hour	25 km :: Global	N/A :: Top of Atmosphere
CERES Radiative Fluxes and Clouds (CRS)	Depends on cloud or flux parameters	N/A :: 1 hour	25 km :: Global	4-18 levels :: Top to Surface
Hourly Gridded Fluxes and Clouds (FSW)	Depends on cloud or flux parameters	N/A :: 1 hour	1.25 x 1.25 deg :: Global	4-18 levels :: Top to Surface
*Synoptic Gridded Fluxes and Clouds (SYN)***	Depends on cloud or flux parameters	3 hour :: N/A	1.25 x 1.25 deg :: Global	4-18 levels :: Top to Surface
*Monthly Regional Fluxes and Clouds to Surface (AVG)***	2 W/m**2 LW; 3 W/m**2 SW; variable for clouds and other fluxes	1 hour :: 1 month	1.25 x 1.25 deg :: Global	4-18 levels :: Top to Surface
*Zonal Monthly Regional Fluxes and Surface to Clouds (ZAVG)***	1 W/m**2 LW; 2 W/m**2 SW; variable for clouds and other fluxes	N/A :: 1 month	1.25 deg zone :: Global	4-18 levels :: Top to Surface
*Surface Radiation Budget (SRB)***	Depends on cloud or flux parameters	N/A :: 1 hour	1.25 x 1.25 deg :: Global	4-18 levels :: Top and Surface
*Monthly Top of Atmosphere and Surface Radiation Budget Averages (SRBAVG)***	Depends on cloud or flux parameters	N/A :: 1 month	1.25 x 1.25 deg :: Global	N/A :: Top and Surface

NOTES:
* Data products constructed with three-satellite CERES observations using ERBE analysis methods for retrospective climate analysis
** Data products constructed with three-satellite CERES observations using two scanners and cloud imager data (VIRS, MODIS) for improved accuracy

DORIS • SSALT • AMR

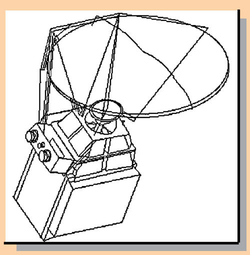
DOPPLER ORBITOGRAPHY AND RADIOPOSITIONING INTEGRATED BY SATELLITE



Key DORIS Facts

- Selected for flight on EOS Radar ALT
- Heritage: TOPEX/Poseidon, SPOT-2, SPOT-3
- Precision orbit determination system
- Provides orbital positioning information and ionospheric correction for SSALT
- Ready for installation on SPOT-4, SPOT-5
- Prime Contractors: Dassault Electronique (receiver), CEIS Espace and SOREP (beacons), CEPE (ultra stable oscillators [USO]), and STAREC (antennas)
- Responsible Center: Centre Nationale d'Etudes Spatiales (France)

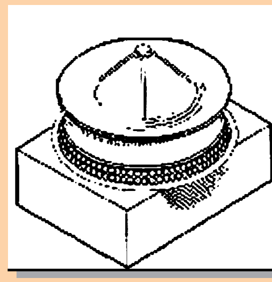
ALTIMETRY MICROWAVE RADIOMETER



Key AMR Facts

- Selected for flight on EOS Radar ALT
- Heritage: TOPEX/Poseidon, Seasat, Nimbus-7
- Tri-frequency microwave radiometer
- Provides atmospheric water vapor profile measurements for SSALT
- Total water vapor along the path viewed by the altimeter
- In-house Jet Propulsion Laboratory development

SOLID-STATE ALTIMETER



Key SSALT Facts

- Selected for flight on EOS Radar ALT
- Heritage: Poseidon radar altimeter
- Dual-frequency radar altimeter
- Maps the topogaphy of the sea surface
- Measures ocean wave height and wind speed, and provides information on the ocean surface current velocity
- Prime Contractor: Alcatel Espace
- Responsible Center: Centre Nationale d'Etudes Spatiales (France)

Collectively, DORIS, SSALT, and AMR make up the instrumentation for the radar altimetry mission (Radar ALT).

DORIS Parameters

Onboard DORIS receiver accurately measures the Doppler shift on both transmitted frequencies (401.25 and 2,036.25 MHz) received from an orbit determination beacon (ODB) station

Network of ~50 ODBs located worldwide

Mass:
Receiver: 12 kg
USO: 1.2 kg
(Total mass for a dual string configuration is 28 kg.)
Antenna: 2 kg
USO Shielding: 8 kg
(Depending on magnetic environment.)

Duty cycle: 100%

Power: 20 W (30 W peak)

Data rate: 200 bps

Thermal control: Heat transfer by conduction to mounting surface and by radiation within the instrument module

Thermal operating range: -10-50° C

IFOV: 125° cone (centered on nadir)

Pointing requirements (platform+instrument, 3σ):
Control: 1.5°
Knowledge: 0.2° (depending on the distance between the antenna phase center and th satellite center of mass)

Physical size: 34 × 24 × 21 cm (receiver); 9 × 7 × 11 cm (Ultra Stable Oscillator [USO]); 32 × 27 × 22 cm (USO magnetic shielding)

Antenna: 40 cm height × 16 cm diameter cone

DORIS

DORIS is based upon the accurate measurement of the doppler shift of radiofrequency signals transmitted from ground-based beacons and received on board the spacecraft when it passes over. Measurements are made on two frequencies: 2.03625 GHz for precise doppler measurement and 401.25 MHz for ionospheric correction. The 401.25 MHz is also used for measurement time tagging and auxiliary data transmission. Approximately 50 global all-weather radio beacons are currently in operation.

The separation of the two transmitting frequencies makes it possible to reduce the ionospheric effect to around the centimeter level. Tropospheric refraction is modeled using surface meteorological data from the ground stations which are directly transmitted to the satellite.

DORIS was validated by a prototype flown on the Systeme pour l'Observation de la Terre-2 (SPOT-2) satellite, launched in January 1990. It provides over six thousand measurements per day, which are used to refine data-processing methods and to improve models of the Earth's gravity field. A DORIS instrument now operates aboard the Ocean Topography Experiment (TOPEX/Poseidon) spacecraft, a joint mission between the U.S. and France launched in August 1992.

The DORIS instruments slated for the EOS ALT series will be an upgraded version of those aboard TOPEX/Poseidon. Experience with SPOT-2, SPOT-3, and TOPEX/Poseidon has shown that the instrument operates most efficiently at an altitude between 750 and 1,500 km. However, DORIS can operate from 300 km to several thousand km.

Altitude accuracy (as determined by the altimeter aboard Radar ALT) is affected by the variable water content of the atmosphere, mainly the troposphere. The primary AMR objective involves measuring the radiometric brightness temperature related to water vapor and liquid water in the same field-of-view as the altimeter. In turn, these brightness temperatures are converted to path-delay information required by the altimeter for precise topography measurements. In order to achieve the required 1.2-cm path delay, the absolute accuracy required of AMR is 1 K.

AMR will passively measure microwave radiation continously, and derived data will be used to determine water vapor and liquid water content in the altimeter field-of-view. In its current design, AMR consists of a collecting aperture shared with SSALT, a multifrequency feed assembly that illuminates the collecting aperture; multichannel microwave receivers; a data unit; power supplies; and ground support equipment. An alternative design under consideration has the AMR working through its own deployable antenna and multichannel receivers.

Developed by the Jet Propulsion Laboratory (JPL), AMR operates at frequencies of 18.2, 23, and 34 GHz to provide estimates of total atmospheric water vapor content. By operating simultaneously on three frequencies, the columnar path delay is derived from microwave brightness temperature. The 23 GHz frequency is the primary measurement channel; the 18.2 and 34 GHz channels are used to remove the effects of wind speed and cloud cover, respectively. The 23 GHz channel is redundant. The channels are polarized orthogonal to the SSALT channels to reduce noise. These data allow reduction of the water vapor delay error to 1 cm, permitting an overall altimetric precision of 3 cm. In-flight calibration is provided by three cross-calibrated noise diodes.

AMR Parameters

Measures brightness temperatures in the nadir column at 18.2, 23.8, and 34 GHz

Beamwidth: 1.2° at 18.2 GHz, 1.0° at 23 GHz, and 0.7° at 34 GHz

Temperature resolution: <1 K

System temperature: 800 K

Mass: 15 kg

Duty cycle: TBD

Power: 15 W

DC supply bus: Unregulated 23-35 V

Data rate: 100 bps

Thermal control by: Thermal control on the AMR is by conduction through the mounting feet to the satellite structure. The AMR box is internally mounted, with no direct exposure to space.

Thermal operating range: 5-35° C

Pointing requirements (platform+instrument, 3σ):
Control: <0.3° (electrical boresight to SSALT boresight)
Knowledge: <0.5°
Stability: <0.5°
Jitter: <0.5°

Physical size: 25 × 25 × 20 cm

SSALT Parameters

Transmitted pulse width of 105 µsec

Pulse repetition frequency of 2100 Hz (1800 for Ku band and 300 for C band)

Maximum radio frequency output power to antenna of 40 dBm (Ku band) and 46 dBm (C band)

Mass: 48 kg for a dual frequency configuration

Duty cycle: 100%

Power: 48 W (18 W RFU, 30 W PCU)

DC supply bus: Unregulated 21-32 V

Transmission frequency: 13.575 GHz, 5.3 GHz

Data rate: 15 kbps (including wave form data and on-board estimated parameters)

Thermal control by: Heat transfer by conduction to mounting surface and by radiation within the instrument module

Thermal operating range: -5-35° C

IFOV: 20° cone (centered on nadir)

Pointing requirements (platform+instrument, 3σ):
Control (Satellite): 0.33° (3σ)
Knowledge: <0.1°

Physical size: 40.4 × 28 × 23.2 cm (RFU); 39 × 23.1 × 20.2 cm (PCU)

SSALT will share a NASA-provided 8-kg antenna with AMR—a 5-frequency, 1.2-m offset, parabolic reflector with a circular, linear-polarized beam.

SSALT is a nadir-looking radar altimeter that maps the topography of the sea surface. 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, SSALT provides 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 research contributions include the study of the variations in sea level 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.

SSALT was developed by Alcatel Espace Systems (ATES) under contract from CNES Toulouse Space Center. This altimeter is being flown on TOPEX/Poseidon as an experimental instrument to allow validation of the accuracy, operation, and signal processing of a small-volume, lightweight, low-power altimeter. SSALT uses the same antenna as the NASA Altimeter (ALT) aboard TOPEX/Poseidon, but operates at the single frequency of 13.6 GHz. The ionospheric-electron correction is provided by a model that makes use of the simultaneous dual-frequency measurements of the DORIS tracking system. Both the operating principles and the expected performance of the NASA and CNES altimeters are similar; however, SSALT has only one-fourth the mass, volume, and power consumption of the NASA instrument. Moreover, the telemetry data rate is reduced by a factor of seven because of more extensive onboard processing. SSALT should be considered a prototype in its present application, but a flight-proven concept by the time of the first EOS ALT launch in 1999.

SSALT is being upgraded for Radar ALT by adding a second frequency of 5.3 GHz, as well as changing to digital technology and using a new, more powerful rad-hard microprocessor while keeping the same mass and size as the single frequency altimeter.

Altimetric measurement by radar determines the distance of the satellite from the surface of the sea. The slope of the surface can then be inferred, which is directly related to the speed of ocean currents. SSALT will help establish global, long-term trends of ocean currents, which will assist in weather prediction and understanding of the hydrologic cycle.

Team Leader To Be Determined

The Radar ALT mission is a collaborative effort between NASA and CNES, with the details of the partnership currently being negotiated. NASA will select the U.S. Team Leader and science team members through a competitive peer review process, evaluating the merit of U.S. proposals to use data from these instruments to address key issues in global climate change. CNES will identify the French scientists who will participate as team members and the individual to serve as the French Team Leader.

Team Members

The selected investigators and those identified by CNES will make up the international science team.

For Further Information

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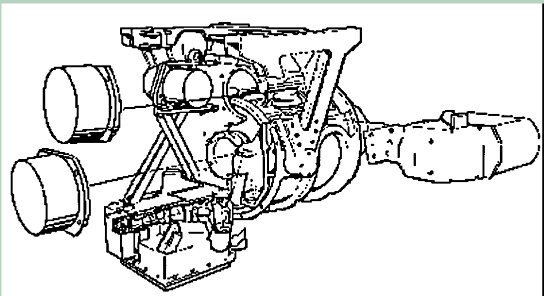
Radar Altimetry Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Altimetry Sensor Data Record	:: 0.25 dB	20 / second	0.35 km :: Earth	N / A :: Surface
Altimetry Geophysical Data Record		1 / second	7 km :: Ocean	N / A :: Surface
Sea_Surface Topography Map	5 cm ::	1 / (10 day)	25 km :: Ocean	N / A :: Surface

NOTE: These standard data products are preliminary pending negotiation and agreement with the responsible EOS investigators

EOS Color

EOS Ocean Color Instrument



Key EOS Color Facts

- Selected for flight as EOS Color
- Heritage: CZCS, SeaWiFS
- Advanced ocean color imager
- Furthers understanding of the role of oceans in the global carbon cycle, fluxes of trace gases at the air-sea interface, and ocean primary productivity
- Follow-on to the SEASTAR/SeaWiFS mission
- Data purchase misson
- Launch scheduled for 1998
- Instrument developer and/or operator yet to be determined

The EOS Ocean Color Instrument is a second generation sensor, based on the Coastal Zone Color Scanner (CZCS) on Nimbus-7 and the SeaStar/Sea-Viewing Wide Field Sensor (SeaWiFS) planned for launch in 1995. SeaStar/SeaWiFS is being conducted as a NASA data purchase from a commercial satellite operator. The EOS Color mission (with a sole SeaWiFS-type instrument as its payload) has been approved to maintain continuity of the data set. EOS Color will have the same basic specifications as the SeaStar/SeaWiFS mission; however, the instrument developer and/or operator have yet to be determined. Instrument specifications include the following:

- Near-polar, sun-synchronous, descending orbit; 705-km altitude; noon ±15 min equatorial crossing time
- Visible, near-infrared ocean color imager, with +20°, 0°,and -20° scan plane tilt, four gain settings (×1, ×2, lunar, and solar diffuser), solar diffuser, and lunar view calibration
- 100% duty cycle over daylight portions of the Earth
- 1.1-km global coverage at nadir, with a swath of ±58.3° (2,800 km)
- Direct broadcast in a High-Resolution Picture Transmission (HRPT)-like format.

Local, high-resolution data will be available via direct broadcast; recorded global data coverage will be transmitted to a ground station, then forwarded to Goddard Space Flight Center (GSFC) for analysis and distribution. These data will be used to study ocean biogeochemistry and its role in the global carbon cycle and as a feedback on physical phenomena, such as heat storage in the upper ocean and cloud albedo. Specific science objectives are to:

- Determine the magnitude and variability of the annual cycle of primary production by marine phytoplankton on a global scale

- Quantify the role of oceans in the global carbon and biogeochemical cycles
- Quantify relationships between ocean physics and large-scale patterns of productivity
- Determine the distribution and timing of spring phytoplankton blooms
- Visualize the physics behind mixing of ocean and coastal currents and eddies
- Advance scientific and technical capability in satellite ocean color observation, data processing, and analysis.

Science Team Members

The members of the Moderate-Resolution Imaging Spectroradiometer (MODIS) Science Team who possess an ocean research emphasis are currently advising NASA on ocean color missions, and will become members of the EOS Color Science Team. NASA will solicit additional proposals and, through a peer review process, select the scientists and Principal Investigator who will lead studies using EOS Color data. In tandem, these investigators will form the EOS Color team, advising NASA on ocean color mission requirements and assuming responsibility for algorithm development for the EOS Color mission.

For Further Information

NASA Research Announcement, 1992: Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) Global Ocean Primary Production. Office of Space Science and Applications, NRA-92-OSSA-7 (April 29).

EOS Color Parameters

Single eight-channel opto-mechanical scanner with viewing angles of +20°, 0°, and -20° in the velocity direction

Eight spectral bands in the range 402-885 nm

Radiometric accuracy <5% absolute each band

Frequent solar calibration; monthly lunar calibration

Relative precision <1% linearity of signal output to radiance

Precision <5% band to band (over 0.5-0.9 full scale)

Polarization sensitivity <2% worst case, all scan and tilt angles

Bright target recovery <10 samples

Dynamic range of 10 bits; four gain settings in each channel (0.75, 1.0, 1.5, 2.5)

Pixel location knowledge 1.0 km

Noon ±15 minute equatorial crossing time, descending orbit

Swath width: 2,800 km (±58.3°) provides daily global coverage

Spatial resolution: 1.1 km (LAC) and 4.5 km (GAC)

Spectral Bands (Minimum specification)

BAND	WAVELENGTH RANGE (nm)	SATURATION RADIANCE*	INPUT RADIANCE*	SNR**
1	402-422	13.63	9.10	499
2	433-453	13.25	8.41	674
3	480-500	10.50	6.56	667
4	500-520	9.08	5.64	640
5	545-565	7.44	4.57	596
6	660-680	4.20	2.46	442
7	745-785	3.00	1.61	455
8	845-885	2.13	1.09	467

* mW/cm^2 µm steradian, gain 1
** Measured at input radiance, at all tilt and sun angles. SNR is the mean of 100 samples divided by the standard deviation of the samples at a specified input radiance

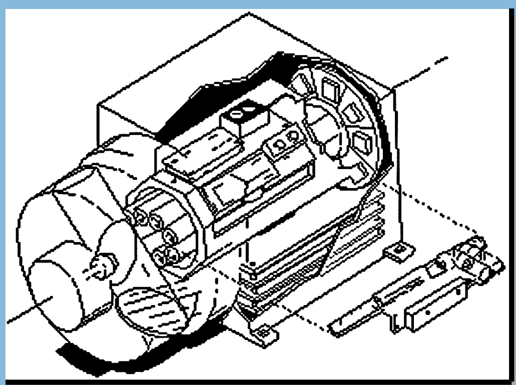
EOS Color Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Chlorophyll_a Pigment Concentration	30-60% (Case I), 50% (Case II)::	1/day, 1/week/ 1 month	1 km :: Ocean-I & II/Regional, Local	N/A

NOTE: These standard data products are preliminary pending peer review and agreement with the responsible EOS investigators

EOSP

Earth Observing Scanning Polarimeter



Key EOSP Facts

- Selected for flight on EOS AM-2 and AM-3
- Heritage: Pioneer Venus CPP, Galileo PPR
- Provides global aerosol distribution and cloud properties such as optical thickness and phase
- Phase C/D start expected in 1999
- Algorithm development to continue
- Responsible Center: NASA/ Goddard Space Flight Center

EOSP will provide global maps of cloud and aerosol properties from retrievals of 12-channel radiance and polarization measurements in the visible and near-infrared (0.41 to 2.25 µm). The EOSP will scan its 10-km nadir instantaneous field-of-view from limb to limb in either the cross-track or along-track direction. Polarization and radiance measurements as a function of the specific scattering geometries will be used to retrieve aerosol and cloud properties including optical thickness, particle size, liquid/ice phase, and cloud-top pressure. A primary objective is the characterization of the global aerosol distribution, its spatial and temporal variability, and the corresponding impact on climate through direct radiative effects and indirect effects as cloud condensation nuclei. EOSP data will also be used to provide atmospheric corrections for clear-sky ocean and land observations and to investigate the potential for obtaining information on vegetation and land surface characteristics.

By measuring the polarization as well as the radiance of the sunlight scattered by the atmosphere and surface, EOSP can exploit the much greater sensitivity of the linear polarization degree to the particular physical characteristics of the scattering particles or surface. For observations of cloudy regions, the relative contributions to the polarization by the scattering from the cloud particles as compared to the highly wavelength-dependent Rayleigh scattering by the atmosphere can be used to infer the cloud-top pressure. Because of the significant differences in the linear polarization corresponding to the spherical versus non-spherical particles with sizes on the order of those typical for clouds, EOSP observations will permit the identification of the cloud-top particle phase as liquid water or ice. The dependence of the polarization on particle size will allow its retrieval using algorithms that also utilize the multispectral radiance information.

For observed regions that are essentially cloud free, the objective is to retrieve aerosol characteristics. A crucial step in this retrieval process is the discrimination of truly cloud-free scenes from those that have optically thin, or subvisible clouds. The substantial differences in the polarization signatures for the cloud particles in contrast to the much smaller aerosol particles will be employed to distinguish these cases. While the optically thin conditions corresponding to cloud-free scenes present an advantage for polarization observations owing to the higher degree of polarization associated with less multiple scattering, there is the increased complexity of the contribution by the surface to the observed polarization and radiance. The separation of surface and aerosol contributions will rely upon techniques using both wavelength-dependent characteristics and sensitivity to observer zenith angle.

EOSP products will fall into three major categories: Atmospheric cloud properties, aerosol properties, and atmospheric correction radiances to be furnished to the other surface imagers on the EOS platform. EOSP data products will include the following:

- Cloud-top pressure, with 30-m vertical resolution and 40-km horizontal resolution
- Cloud particle phase at cloud top, with 100-km horizontal resolution
- Cloud particle size at cloud top, with 100-km horizontal resolution
- Cloud optical thickness, with 40-km horizontal resolution
- Aerosol optical thicknesses at an altitude range of 0 to 35 km, with 40-km horizontal resolution
- Atmospheric correction radiances covering the spectral region from 0.41 to 2.25 µm, with 40-km horizontal resolution.

EOSP Parameters

Simultaneous measurement of radiance and linear polarization degree in 12 spectral bands from 0.41 to 2.25 µm

Spectral bidirectional reflectance distribution function accurate to 5%

Polarization accurate to 0.2%

Swath: ±65° (limb-to-limb scan)

Spatial resolution: 10 km at nadir

Mass: 19 kg

Duty cycle: 100%

Power: 14 W (normal),
22 W (peak)

Data rate: 44 kbps (orbit average), 88 kbps (peak, daylight only)

Thermal control by: Heaters and radiators; 185 K radiator for SWIR detector cold focal plane

Thermal operating range: 0-40°C

FOV: ±65° limb to limb

Instrument IFOV: 14.2 mrad

Pointing requirements (platform+instrument, 3σ):
Control: 3,600 arcsec
Knowledge: 150 arcsec
Stability: 100 arcsec per 10 sec
Jitter: 100 arcsec per 10 sec

Physical size: 51 × 26 × 81 cm (stowed); 51 × 56 × 81 cm (deployed)

Principal Investigator
Larry D. Travis

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

Co-Investigators

F. Gerald Brown
Santa Barbara Research Center

Andrew Lacis
NASA/Goddard Institute for Space Studies

William B. Rossow
NASA/Goddard Institute for Space Studies

Edgar E. Russell
Santa Barbara Research Center

For Further Information

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

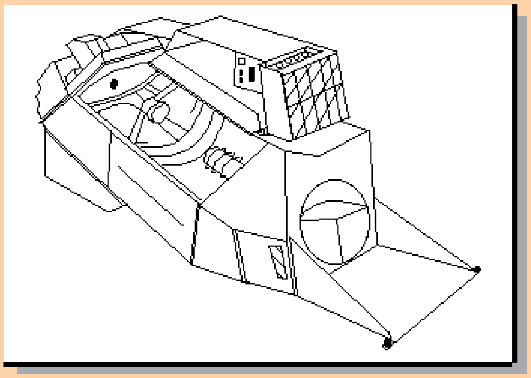
EOSP Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Level-1B Polarization	0.2% :: 0.1%	1 / day [d]	10-70 km :: Global	N / A :: N / A
Level-1B Radiance	5% :: 1%	1 / day [d]	10-70 km :: Global	N / A :: N / A
Aerosol Optical Thickness	0.05 :: 10%	1 / day [d]	40 km :: Global	Column :: Atmosphere
Cloud Product		1 / day [d]	40-100 km :: Global	30 mb, Column :: Cloud

NOTE: These standard data products are preliminary pending peer review and agreement with the responsible EOS investigators

ETM+

Enhanced Thematic Mapper Plus



Key ETM+ Facts

- Selected for flight on Landsat-7
- Heritage: Landsat-4, -5 and -6
- Imaging radiometer
- Provides high spatial, multispectral images of the sunlit land surface
- 16-day repeat cycle
- 7 spectral bands from visible to thermal infrared plus panchromatic band
- Scheduled for 1998 launch
- Prime Contractor: Hughes SBRC
- Responsible Center: NASA/ Goddard Space Flight Center

The Enhanced Thematic Mapper Plus (ETM+) is an operational instrument to be flown on the Landsat-7 satellite in 1998. ETM+ will provide synoptic, repetitive, multispectral, high-resolution, digital image coverage of the Earth's land surfaces. Since 1972, the Landsat Program has provided calibrated land surface digital imagery to a broad user group including the agricultural community, global change researchers, state and local governments, commercial users, international users, and the military. The Landsat-7 mission will extend the data base of the Earth's surface into the next century.

The ETM+ instrument is an improved version of the Thematic Mapper instruments that flew on Landsat-4 and -5. Like the earlier instruments, the ETM+ will acquire data for six visible, near-infrared, and short wave infrared spectral bands at a spatial resolution of 30 meters (see Spectral Band Summary table).

The ETM+ instrument also incorporates a 15-meter resolution panchromatic band as well as improved ground resolution for the thermal infrared band (60 m vs. 120 m). Incorporation of in-flight full and partial aperture solar calibration will improve the overall radiometric accuracy to 5 percent. The ETM+ will provide data that are sufficiently consistent in terms of acquisition geometry, spatial resolution, spectral characteristics, and calibration with previous Landsat data to meet requirements for global change research. The mission will generate and periodically refresh a global land mass archive with substantially cloud-free, sunlit data.

ETM+ data will be used primarily to characterize and monitor change in land cover and land surface processes. The high spatial resolution and synoptic coverage to afford land surface repetitive coverage will support observations of seasonal variations in land surface processes.

The Landsat-7 satellite will operate in a circular, sun-synchronous orbit with an inclination of 98.2 degrees, and altitude of 705 km, and a descending node equatorial crossing time of 10:00 am plus or minus 15 minutes. The orbit altitude and inclination will be controlled such that the ground track will be maintained on the Landsat Worldwide Reference System to an accuracy of 5 km at the equator and a repeat cycle of 16 days (233 orbits). The 185 km swath of coverage provided by the ETM+ field-of-view affords a global view every 16 days. The satellite will either directly downlink ETM+ data to international ground receiving stations at a rate of 150 Mbps or store data in an on-board solid-state recorder. The stored data, as well as real-time continental U.S. data, will be downlinked to the Landsat-7 ground station located at the EROS Data Center (EDC) in South Dakota. Data received at the EDC will be processed for archiving and distribution by the Land Processes DAAC.

Beyond ETM+ on the Landsat-7 satellite, NASA is currently exploring advanced technologies to accomplish Landsat observational requirements and data continuity. The plan is to demonstrate such alternative technology in tandem with Landsat-7 in time to replace ETM+ in the EOS AM-2 timeframe. This Landsat Advanced Technology Instrument (LATI) will be integrated into the AM-2 mission.

ETM+ Parameters

Whiskbroom scanning radiometer

3 VIS, 1 NIR, 2 SWIR, 1 TIR, 1 pan spectral bands 30 m resolution in VIS, NIR, SWIR; 60 m TIR; 15 m pan Periodic (seasonal) global coverage of land surfaces

Swath: 185 km (±7.5°)

Mass: 425 kg

Power: 590 W (imaging), 175 W (Standby)

Duty cycle: 15% imaging

Thermal control: 90 K Radiative cooler

Pointing requirements:
Control: 60 arcsec (1 sigma)
Knowledge: 45 arcsec (1 sigma)
Jitter: 4 arcsec (1 sigma)

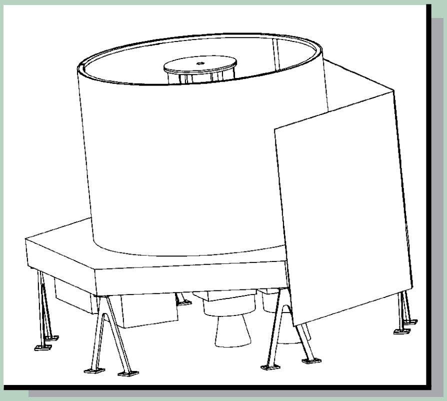
Physical Size:
Scanner Assembly: 196 × 114 × 66 cm
Auxilliary Electronics: 90 × 66 × 35 cm

ETM+ Spectral Band Summary

SPECTRAL BAND	HALF-AMPLITUDE BANDWIDTH (µm)	IFOV SIZE (µr)	NOMINAL GROUND SAMPLE SIZE (m)
Panachromatic	0.50-0.90	18.5 x 21.3	15
1 (VIS)	0.45-0.52	42.6	30
2 (VIS)	0.52-0.60	42.6	30
3 (VIS)	0.63-0.69	42.6	30
4 (NIR)	0.76-0.90	42.6	30
5 (SWIR)	1.55-1.75	42.6	30
6 (TIR)	10.42-12.50	85.2	60
7 (SWIR)	2.08-2.35	42.6	30

GLAS

Geoscience Laser Altimeter System



Key GLAS Facts

- Selected for flight on EOS Laser ALT
- Heritage: Airborne and Spaceborne Laser Altimetry and Lidar Systems; Satellite Laser Ranging Systems
- Nadir-pointed Laser Altimeter
- Measures ice-sheet topography and temporal changes in topography; cloud heights, planetary boundary heights, and aerosol vertical structure; and land and water topography
- NASA / Goddard Space Flight Center in-house development

GLAS is a laser altimeter designed to measure ice-sheet topography and associated temporal changes, as well as cloud and atmospheric properties. In addition, operation of GLAS over land and water will provide along-track topography. GLAS is a descoped version of the Geoscience Laser Ranging System (GLRS), focusing solely on the laser altimetry science mission. For ice-sheet applications, the laser altimeter will measure height from the spacecraft to the ice sheet, with an intrinsic precision of better than 10 cm with a 70-m surface spot size. The height measurement, coupled with knowledge of the radial orbit position, will provide the determination of topography. Characteristics of the return pulse will be used to determine surface roughness. Changes in ice-sheet thickness at a level of a few tens of cm (anticipated to occur on a subdecadal time scale) will provide information about ice-sheet mass balance and will support prediction analyses of cryospheric response to future climatic changes. The ice-sheet mass balance and contribution to sea-level change will also be determined. The accuracy of height determinations over land will be assessed using ground slope and roughness. The height distribution will be digitized over a total dynamic range of several tens of m.

Along-track cloud and aerosol height distributions will be determined with a vertical resolution of 75 to 200 m and a horizontal resolution from 150 m for dense cloud to 50 km for aerosol structure and planetary boundary layer height. Unambiguous measurements of cloud height and the vertical structure of thin clouds will support studies on the influence of clouds for radiation balance and climate feedbacks. Polar clouds and haze will be detected and sampled with much greater reliability and accuracy than can be achieved by passive sensors. Planetary boundary layer height will be directly and accurately measured for input into surface flux and air-sea and air-land interaction models. Direct measurements of aerosol vertical profiles will contribute to understanding of aerosol-climate effects and aerosol transport.

The GLAS laser is a diode pumped, Q-switched Nd:YAG laser with energy levels of 100 mJ (1.064 µm) and 50 mJ (0.532 µm). The pulse repetition rate is 40 pulses/sec, and the beam divergence is approximately 0.1 mrad. The infrared pulse is used for surface altimetry, and the green pulse is used for atmosphere measurements. The altimeter uses an 80-cm diameter telescope.

Team Leader
Bob E. Schutz

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

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

Dr. Schutz serves as the President-elect of the American Geophysical Union Geodesy Section, as President of Comission VIII in the International Association of Geodesy and as a member of the Governing Board of the International GPS Service for Geodynamics.

GLAS Parameters

Uses Nd:YAG laser with 1.064- and 0.532-µm output

Cloud and aerosol data are extracted from the green pulse

Height measurements: Determined from the round-trip pulse time of the infrared pulse flight

Swath: Nadir viewing

Spatial Resolution: At 40 pulses per second, the centers of 70-m spots are separated in the along-track direction by 170 m for a 705-km altitude orbit; the cross-track resolution is determined by the 182-day ground track repeat cycle which yields 15-km resolution at the equator and 2.5 km at 80° latitude.

Mass: 200 kg

Duty cycle: 100%

Power: 225 W average

Data rate: <200 kbps

Thermal control by: Radiators supplemented by heaters, heat pipes

Thermal operating range: 0-25°C

FOV: Nadir only

Instrument IFOV: ~70 m laser footprint at nadir at 1.064 µm

Pointing Requirements (platform+instrument, 3σ):
Control: ~90 arcsec (all axes)
Post-processing knowledge: 5 arcsec (all axes, to be provided by instrument-mounted star trackers)
Stability: 2 arcsec/sec
Jitter: <2 arcsec for periods less than 1 sec

Position requirements: Post-processing determination of radial orbit for ice sheet to <5 cm and along-track position to <20 cm (to be provided by instrument-mounted GPS receiver and SLR array)

Physical size: 100 × 100 × 80 cm

Science Team Members

Charles R. Bentley
University of Wisconsin Madison

Jack L. Bufton
NASA/Goddard Space Flight Center

Thomas A. Herring
Massachusetts Institute of Technology

Jean-Bernard Minster
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NASA/Goddard Space Flight Center

Robert H. Thomas
NASA Headquarters

H. Jay Zwally
NASA/Goddard Space Flight Center

For Further Information

Cohen, S., J. Degnan, J. Bufton, J. Garvin, and J. Abshire, 1987: The geoscience laser altimetry/ranging system. *IEEE Trans. Geoscience Remote Sensing*, **GE-25**, 581-592.

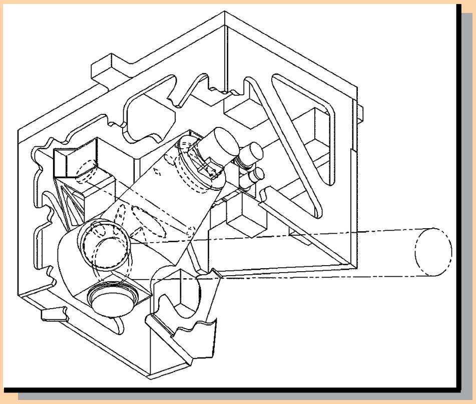
GLAS Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Level-1A Product				
Level-1B Non-instrument Correction		continuous	:: Global	:: Global
Level-1B Altimeter Height	200 mm (ice) - 5000 mm (land) ::	40 Hz	170 m :: Land / Cryosphere	N / A :: Cryosphere
Level-1B Product, Atmosphere	10% ::	1 / (2-16 day)	1 - 100 km :: Global	75 m :: Atmosphere
Aerosol Vertical Structure	20% (profile), 150 m (Boundary Layer Height) ::	1 / (2-16 day)	2 - 100 km :: Global	150 m (profile), N / A (Boundary Layer Height) :: Atmosphere
Cloud Height for Multiple Layers	75 m ::	1 / (2-16 day)	0.2 - 10 km :: Global	N / A :: Cloud
Ice Sheet Elevation	200 mm (single measurement up to 3 deg surface slope) ::	2 / year	170 mm (Along Track) x 2.5 km avg. (Cross Track) :: Land / Cryosphere	N / A :: Cryosphere
Ice Sheet Roughness	10% ::	2 / year	50 km :: Land / Cryosphere	N / A :: Cryosphere
Thin Cloud/Aerosol Optical Depth	20% ::	1 / (2-16 day)	2 - 100 km :: Global	N / A :: Atmosphere
Land Topography	1 - 5 m ::	2 / year	170 mm (Along Track) x 15 km (equator) (Cross Track) :: Land	N / A :: Surface
Vegetation Topography	1 - 5 m ::	2 / year	170 mm (Along Track) x 15 km (equator) (Cross Track) :: Land	N / A :: Surface

NOTE: These standard data products are preliminary pending peer review and agreement with the responsible EOS investigators

HIRDLS

High Resolution Dynamics Limb Sounder



Key HIRDLS Facts

- Selected for flight on EOS CHEM series
- Heritage: LRIR (Nimbus-6), LIMS and SAMS (Nimbus-7), ISAMS and CLAES (UARS)
- Observes global distribution of temperature and concentrations of O_3, H_2O, CH_4, N_2O, NO_2, HNO_3, N_2O_5, CFC11, CFC12, $ClONO_2$, and aerosols in the upper troposphere, stratosphere, and mesosphere
- Scanning infrared limb sounder
- 21 photoconductive HgCdTe detectors cooled to 65 K; each detector has a separate band pass interference filter
- Joint program between Oxford University and National Center for Atmospheric Research
- Prime Contractors: Lockheed Martin (U.S.) and Matra-Marconi Space (U.K.)

HIRDLS is an infrared limb-scanning radiometer designed to sound the upper troposphere, stratosphere, and mesosphere to determine: temperature; the concentrations of O_3, H_2O, CH_4, N_2O, NO_2, HNO_3, N_2O_5, CFC11, CFC12, $ClONO_2$, and aerosols; and the locations of polar stratospheric clouds and cloud tops. The goals are to provide sounding observations with horizontal and vertical resolution superior to that previously obtained; to observe the lower stratosphere with improved sensitivity and accuracy; and to improve understanding of atmospheric processes through data analysis, diagnostics, and use of two- and three-dimensional models.

HIRDLS performs limb scans in the vertical at multiple azimuth angles, measuring infrared emissions in 21 channels ranging from 6.12 to 17.76 µm. Four channels measure the emission by CO_2. Taking advantage of the known mixing ratio of CO_2, the transmittance is calculated, and the equation of radiative transfer is inverted to determine the vertical distribution of the Planck black body function, from which the temperature is derived as a function of pressure. Once the temperature profile has been established, it is used to determine the Planck function profile for the trace gas channels. The measured radiance and the Planck function profile are then used to determine the transmittance of each trace species and its mixing ratio distribution.

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

Overall science goals of HIRDLS are to observe the global distributions of temperature and several trace species in the stratosphere and upper troposphere at high vertical and horizontal resolution. Specific issues to be investigated include:

- Fluxes of mass and chemical constituents between the troposphere and stratosphere
- Chemical processes, transport, and mixing (particularly in the lower stratosphere)
- Momentum, energy, heat, and potential vorticity balances of the upper troposphere and middle atmosphere
- Geographically and seasonally unbiased long-term climatologies and interannual variability of middle atmosphere temperature, constituents, dynamical fields, and gravity waves
- Tropospheric cloud-top heights
- Tropospheric temperature and water vapor retrievals (by providing high-resolution limb data for joint retrieval with EOS nadir sounders)
- Diagnostic studies of atmospheric dynamics, chemistry, and transport processes to test and improve models of these processes.

The instrument has a long heritage extending back to Nimbus-4, and will obtain profiles over the entire globe, including the poles, both day and night. Complete Earth coverage (including polar night) can be obtained in 12 hours. 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. Vertical profiles are spaced every 4° in latitude and longitude, with 1- to 1.5-km vertical resolution. Observations of the lower stratosphere and upper troposphere are improved through the use of special narrow and more-transparent spectral channels. The instrument is programmable; thus, a variety of observation modes can be used, and may be adapted in flight to observe unexpected geophysical events.

HIRDLS Parameters

Spectral range: 6 to 18 µm

Standard profile spacing:
4° longitude × 4° latitude, and 1-km vertical resolution; programmable to other modes and resolutions

Swath: Typically six profiles across 2,000- to 3,000-km-wide swath

Spatial resolution: Profile spacing 400 × 400 km horizontally (equivalent to 4° long x 4° lat) × 1 km vertically; averaging volume for each data sample 1 km vertical × 10 km across × 400 km along line-of-sight

Mass: 169 kg

Duty cycle: 100%

Power: 169 W (average),
230 W (peak)

Data rate: 50 kbps avg., 100 kbps peak

Thermal control by: Paired Stirling cycle coolers, heaters, sun baffle, radiator panel

Thermal operating range: 20-30° C

Scan range: Elevation, 22.1° to 27.3° below horizontal, -21° (sun side) to +43° (anti-sun side)

Detector IFOV: 1 km vertical × 10 km horizontal

Platform pointing requirements (platform+instrument, 3σ):
Control: 900 arcsec (all axes)
Knowledge: 250 arcsec (all axes)
Stability: 30 arcsec/sec per axis
Jitter: TBD

Physical size: 130 × 83 × 125 cm

Co-Principal Investigators

John Barnett

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

John Gille

John Gille received a B.S. in Physics, magna cum laude, from Yale University, an M.A. in Physics from Cambridge University, and a Ph.D. in Geophysics from MIT. 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, and was Principal Investigator on LRIR, which flew on Nimbus-6. He has been involved in CLAES collaboration, 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 and the NASA Exceptional Scientific Achievement Medal.

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For Further Information

Gille, J., and J. Barnett, 1992: The High-Resolution Dynamics Limb Sounder (HIRDLS). An instrument for the study of global change. *The Use of EOS for Studies of Atmospheric Physics*, J. Gille and G. Visconti, Eds., North-Holland, 433-450.

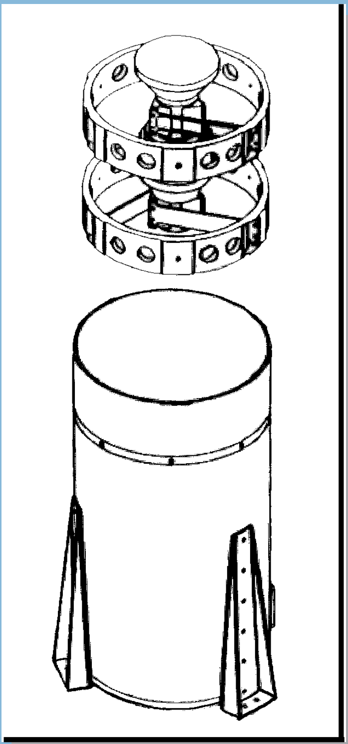
HIRDLS Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Level-1B Product			400 km :: Global	
Aerosol Extinction Coef (4 channels)	5-10% :: 1-10%	2/day [d,n]	400 km :: Global	1 km :: 5-60 km (given accuracies for 7-30 km)
CFC-11 (CFC13) Conc	5-10% :: 1-10%	2/day [d,n]	400 km :: Global	1 km :: 5-50 km (given accuracies for 7-30 km)
CFC-12 (CF_2Cl_2) Conc	5-10% :: 1-10%	2/day [d,n]	400 km :: Global	1 km :: 5-55 km (given accuracies for 7-30 km)
CH_4 Conc	5-10% :: 1-10%	2/day [d,n]	400 km :: Global	1 km :: 5-65 km (given accuracies for 7-65 km)
$ClONO_2$	5-10% :: 3-15%	2/day [d,n]	400 km :: Global	1 km :: 15-65 km
Cloud Top Altitude	1 km :: 400 m	2/day [d,n]	400 km :: Global	1 km :: 5 - 20 km
Geopotential Height-Gradient	0.04 m/km :: 0.04 m/km	2/day [d,n]	400 km :: Global	1 km :: 5-80 km (given accuracies for 15-80 km)
H_2O Conc	5-10% :: 1-10%	2/day [d,n]	400 km :: Global	1 km :: 5-70 km (given accuracies for 7-70 km)
HNO_3 Conc	5-10% :: 1-10%	2/day [d,n]	400 km :: Global	1 km :: 5-50 km (given accuracies for 10-40 km)
N_2O Conc	5-10% :: 1-10%	2/day [d,n]	400 km :: Global	1 km :: 5-70 km (given accuracies for 7-60 km)
N_2O_5 Conc	5-10% :: 1-10%	2/day [d,n]	400 km :: Global	1 km :: 10-65 km (given accuracies for 15-45 km)
NO_2 Conc	5-10% :: 3-10%	2/day [d,n]	400 km :: Global	1 km :: 5-65 km (given accuracies for 10-55 km)
O_3 Conc	5-10% :: 1-10%	2/day [d,n]	400 km :: Global	1 km :: 5-80 km (given accuracies for 7-80 km)
Temperature/ Pressure Profile	1-2 K :: 0.4-1 K	2/day [d,n]	400 km :: Global	1 km :: 5-80 km (given accuracies for 8-80 km)

NOTE: These standard data products are preliminary pending peer review and agreement with the responsible EOS investigators

LIS

LIGHTNING IMAGING SENSOR



Sensor Head Assembly and Telescope

Key LIS Facts

- EOS-funded instrument selected for flight on TRMM-1
- Staring telescope / filter imaging system that detects the rate, location, and radiant energy of lightning flashes
- Investigates the distribution and variability of lightning over the Earth with storm scale spatial resolution
- 90% detection efficiency under both day and night conditions using background remover and event processor
- In-house NASA / Marshall Space Flight Center development
- Phase C / D start January 1991
- Prototype for geostationary orbit

The calibrated optical LIS will investigate the global incidence of lightning, its correlation with rainfall, and its relationship with the global electric circuit. Conceptually, LIS is a simple device, consisting of a staring imager optimized to locate both intracloud and cloud-to-ground lightning with storm-scale resolution over a large region of the Earth's surface, to mark the time of occurrence, and to measure the radiant energy. It will monitor individual storms within the field-of-view (FOV) for 80 seconds, long enough to estimate the lightning flashing rate. Location of lightning flashes will be determined to within 5 km over a 600 × 600 km FOV.

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

A combination of four methods is used to take advantage of the significant differences in the temporal, spatial, and spectral characteristics between the lightning signal and the background noise. First, spatial filtering is used to match the instantaneous FOV of each detector element in the LIS focal-plane array to the typical cloud-top area illuminated by a lightning event (about 5 km). Second, spectral filtering is applied, using a narrow-band interference filter centered about the strong OI (1) emission multiplet in the lightning spectrum at 777.4 nm. Third, temporal filtering is applied. The lightning pulse duration is of the order of 400 μsec, whereas the background illumination tends to be constant on a time scale of seconds. The lightning signal-to-noise ratio improves as the integration time approaches the pulse duration. Accordingly, an integration time of 2 msec is chosen to minimize pulse splitting between successive frames and to maximize lightning detectability. Finally, a modified frame-to-frame background subtraction is used to remove the slowly varying background signal from the raw data coming off the LIS focal plane. If, after background removal, the signal for a given pixel exceeds a specified threshold, that pixel is considered to contain a lightning event.

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

Principal Investigator
Hugh Christian

Hugh Christian is a graduate of the University of Alaska, and received an M.S. and Ph.D. in Space Physics and Astronomy from Rice University. He has served in various government, private industry, and academic capacities, primarily within his area of expertise: thunderstorms, atmospheric electricity, lightning data acquisition systems, and airborne instrumentation. Since 1980, Dr. Christian has been a space scientist at the Marshall Space Flight Center.

LIS Parameters

Storm-scale (5-km) spatial resolution; 2-msec temporal resolution

Spectral filter to image at 0.777 µm onto a 128 x 128 CCD array detector

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

Swath: 600 × 600 km

Spatial resolution: 5 km

Mass: 20 kg

Duty cycle: 100%

Power: 33 W

Data rate: 6 kbps

Thermal control by: Heater, radiator

Thermal operating range:
0 - 40° C

FOV: 80° x 80°

Instrument IFOV: 0.7°

Pointing requirements (platform+instrument, 3σ):
Control: None
Knowledge: 1 km on ground
Stability: TBD
Jitter: TBD

Physical size:
Sensor head assembly (cylindrical): 20 × 30 cm;
Electronics assembly: 30 × 20 × 30 cm

Co-Investigators

Richard Blakeslee
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Steven J. Goodman
NASA/Marshall Space Flight Center

Douglas M. Mach
University of Alabama

For Further Information

Christian, H.J., R.J. Blakeslee, and S.J. Goodman, 1989: The detection of lightning from geostationary orbit. *J. Geophys. Res.*, **94**, 13,329-13,337.

Christian, H.J., R.J. Blakeslee, and S.J. Goodman, 1992: Lightning Imaging Sensor (LIS) for the Earth Observing System. NASA Technical Memorandum 4350, MSFC, Huntsville, AL.

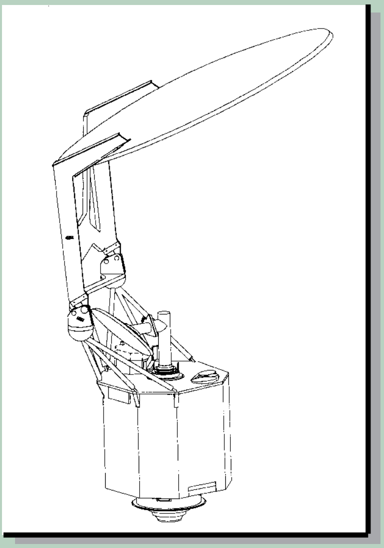
Goodman, S.J., and H.J. Christian, 1993: Global observations of lightning. *Atlas of Satellite Observations Related to Global Change*, Edited by R. Gurney, J. Foster, and C. Parkinson. Cambridge University Press, New York, 191-219.

LIS Data Products

PRODUCT/ COMPONENT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Raw Data	:: 2.4×10^{-4}	2 ms	3.5 km :: Global	N/A
Lightning				
Background Images (Level 1-B Component)	:: 2.4×10^{-4}	2 ms	3.5 km :: Global	N/A
Events (Level 1-B Component)	:: 7.8×10^{-3}	2 ms	3.5 km :: Global	N/A
Groups (Level 2 Component)	:: 7.8×10^{-3}	2 ms	3.5 km :: Global	N/A
Flashes (Level 2 Component)	:: 7.8×10^{-3}	2 ms	3.5 km :: Global	N/A
Areas (Level 2 Component)	:: 7.8×10^{-3}	2 ms	3.5 km :: Global	N/A
Vector Data (Level 2 Component)	:: 1	1 orbit	500 km :: Global	N/A
Browse Data (Level 3 Component)	:: 1	1 orbit	3.5 km :: Global	N/A
Orbit Stats (Level 3 Component)	:: N/A	1 orbit	3.5 km :: Global	N/A

MIMR

MULTI-FREQUENCY IMAGING MICROWAVE RADIOMETER



Key MIMR Facts

- Selected for flight on EOS PM series
- Heritage: SSM/I and SMMR
- Measures precipitation rate, cloud water, water vapor, sea surface winds, sea surface temperature, ice, snow, and soil moisture
- Passive microwave radiometer
- Phase C/D start expected early 1996
- Phase B Contractor: Alenia
- Responsible Center: European Space Agency/European Space Research and Space Technology Centre

MIMR is a passive microwave radiometer provided under a Memorandum of Understanding with the European Space Agency (ESA). The instrument builds upon the successful design of the Special Sensor Microwave/Imager (SSM/I), but provides greater frequency diversity, improved spatial resolution, increased swath width, and improved antenna performance—allowing nearly complete global coverage in less than one day. MIMR will provide three times better resolution than is now available with current passive microwave radiometers. Slated for the EOS PM satellite series, the instrument will observe numerous atmospheric and oceanic parameters, including precipitation, soil moisture, global ice and snow cover, sea surface temperature and wind speed, atmospheric cloud water, and water vapor. Currently, wind direction retrieval is under investigation using polarimetric channels at 37 GHz.

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

MIMR operates at six frequencies, each with horizontal and vertical polarization: 6.8, 10.65, 18.7, 23.8, 36.5, and 89 GHz. MIMR employs nine feedhorns, yielding 20 available channels. The frequencies were chosen to maximize sensitivity to particular parameters of interest and to operate in protected regions of the spectrum. MIMR is designed to have a cross-track swath of 1,250 km at an incidence angle of about 53.7°, which provides 3-day global coverage of the Earth. At high latitudes, i.e., >45°, the overlap between consecutive swaths increases and daily coverage is provided. MIMR data products will include measurements in its 20 channels covering dual polarization from 6.8 to 89 GHz with corresponding 70- to 5.6-km resolution, 1 to 1.5 K accuracy, and 0.2 to 0.7 K radiometric sensitivity and stability.

MIMR-retrieved geophysical products will be servicing operational, climate change, and research application sectors. In particular, liquid water content, water vapor content, sea surface temperature, wind speed, and rain rate over the ocean will be provided to operational meteorological centers; ice concentration, type, extent, ice fraction, and ice temperature will be provided to operational ice forecasting centers, while experimental products such as soil moisture, vegetation index, snow-water equivalent, rain rate over land, stratiform/convective cloud flags, ice in clouds, and heat and radiative fluxes will be mostly subject to further research. All the products will be gridded within the geometry of the original image.

Science Team Members

The MIMR Science Advisory Group is currently composed of the following U.S. Science Team Members, and Canadian, and European Science Advisors:

Roy W. Spencer, U.S. Team Leader
NASA/Marshall Space Flight Center

Christopher Readings, Team Leader
European Space Agency

Robert F. Adler
NASA/Goddard Space Flight Center

MIMR Parameters

External calibration

1.6-m parabolic antenna and rotating drum at ~30 rpm

Multiple feedhorns (9) to cover bands from 6.8 to 90 GHz with 0.2 to 0.7 K radiometric sensitivity and stability

1 to 1.5 K accuracy

Swath: 1,250 km

Spatial resolution: 5.6 km (89 GHz), 14 km (36.5 GHz), 24 km (23.8 GHz), 26 km (18.7 GHz), 45 km (10.65 GHz), 70 km (6.8 GHz)

Mass: 230 kg

Duty cycle: 100%

Power: 172 W (average), 200 W (peak)

Data rate: 100 kbps

Thermal control by: Radiator

Thermal operating range: -10-50° C

FOV: Forward-looking conical scan

Pointing requirements (platform+instrument, 3σ):
Control: 720 arcsec
Knowledge: 0.1°
Stability: 0.1°
Jitter: 0.1°

Physical size: 130 × 150 × 95 cm (stowed); 3000 × 150 × 147 cm (deployed)

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For Further Information

European Space Agency, MIMR Interim Report, Publication Division, ESA/ESTEC, The Netherlands, in press.

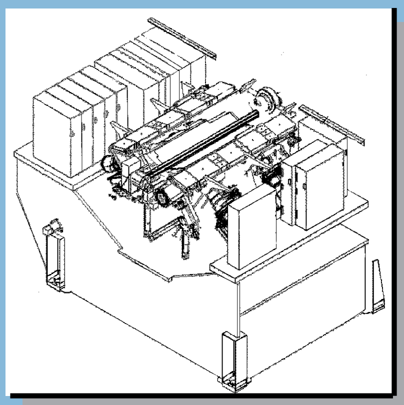
MIMR Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Level-1B Brightness Temperature	0.2 - 0.7 K ::		6 - 60 km :: Global	N/A ::
Precipitation	20 - 40% ::		12 km (Land), 38 km (Ocean) :: Global	N/A :: Surface
Ocean Cloud Water	3 mg/cm^2		23 km :: Ocean	N/A :: Troposphere
Oceanic Water Vapor	0.2 g/cm^2 ::		23 km :: Ocean	Column :: Troposphere
Ocean Surface Wind Speed	1.5 m/s ::		12 km :: Ocean	N/A :: Surface
Sea Surface Temperature	0.5 K ::		60 km :: Ocean	N/A :: Surface
Sea Ice Concentration	7% ::		12 km :: Ocean/Cryosphere	N/A :: Surface

NOTE: These standard data products are preliminary pending peer review and agreement with the responsible EOS investigators

MISR

Multi-angle Imaging SpectroRadiometer



Key MISR Facts

- Selected for flight on EOS AM series
- Heritage: GLL, Wide-Field / Planetary Camera
- Provides top-of-atmosphere, cloud, and surface angular reflectance functions
- Provides global maps of planetary and surface albedo, and aerosol and vegetation properties
- In-house Jet Propulsion Laboratory development
- Phase C / D start January 1991

MISR will routinely provide multiple-angle, continuous sunlight coverage of the Earth with high spatial resolution. The instrument will obtain multidirectional observations of each scene within a time scale of minutes, thereby under virtually the same atmospheric conditions. MISR uses nine individual charge coupled device (CCD)-based pushbroom cameras to observe the Earth at nine discrete view angles: One at nadir, plus eight other symmetrical views at 26.1, 45.6, 60.0, and 70.5° forward and aftward of nadir. Images at each angle will be obtained in four spectral bands centered at 443, 555, 670, and 865 nm. Each of the 36 instrument data channels (4 spectral bands × 9 cameras) is individually commandable to provide ground sampling of 275 m, 550 m, or 1.1 km. The swath width of the MISR imaging data is 360 km, providing global multi-angle coverage of the entire Earth in 9 days at the equator, and 2 days at the poles.

The instrument design and calibration strategies have the goal of maintaining absolute radiometric uncertainty to less than ±3% over bright surfaces and ±6% over dark surfaces, with smaller uncertainties in relative band-to-band and angle-to-angle radiances. These objectives will be met through the use of state-of-the-art detector-based calibration, using on a monthly basis an on-board calibrator consisting of deployable solar diffuser panels and an array of radiation-resistant and high-quantum-efficiency diodes. Semi-annual field calibration exercises are planned to provide a ground-truth verification of the diode performance.

MISR images will be acquired in two observing modes: Global and Local. Global Mode provides continuous planet-wide observations, with most channels operating at moderate resolution and selected channels operating at the highest resolution for cloud screening and classification, image navigation, and stereo-photogrammetry. Local Mode provides data at the highest resolution in all spectral bands and all cameras for selected 300 km × 300 km regions. In addition to data products providing radiometrically calibrated and geo-rectified images, Global Mode data will be used to generate two standard Level 2 science products during ground data processing: the Top-of-Atmosphere (TOA)/Cloud Product and the Aerosol/Surface Product.

The purpose of the TOA/Cloud Product is to enable study, on a global basis, of the effects of different types of cloud fields (classified by their heterogeneity and altitude) on the solar radiance and irradiance reflected to space, and to determine their effects on Earth's climate. Additionally, this product provides a cloud screen for MISR aerosol and surface retrievals.

The aerosol parameters contained within the Aerosol/Surface Product will enable study, on a global basis, of the magnitude and natural variability in space and time of sunlight absorption and scattering by aerosols in the Earth's atmosphere, particularly in the troposphere, and to determine their effects on climate; to improve our knowledge of the sources, sinks, and global budgets of natural and anthropogenic aerosols, and to provide atmospheric correction inputs for surface imaging data acquired by MISR and other instruments, e.g., MODIS and ASTER, that are simultaneously viewing the same portion of the Earth. The surface parameters within the Aerosol/Surface Product are designed to enable improved measures of land surface radiative characteristics, particularly bidirectional and hemispherical reflectances, on a global basis; to provide, in conjunction with MODIS, improved measures of land surface classification, dynamics, and over vegetated terrain, canopy photosynthesis and transpiration rates; and to supplement MODIS studies of the biogeochemical cycle in the tropics by providing atmospherically-corrected ocean color data.

Principal Investigator
David J. Diner

David J. Diner received a B.S. in Physics with honors from the State University of New York at Stony Brook, and an M.S. and Ph.D. in Planetary Science from the California Institute of

MISR Parameters

Nine CCD cameras fixed at nine viewing angles out to 70.5° at the Earth's surface, forward and aftward of nadir, including nadir

Four spectral bands discriminated via filters bonded to the CCD's

Global coverage in 9 days

Swath: 360 km viewed in common by all nine cameras

Spatial sampling: 275 m, 550 m, or 1.1 km, selectable in-flight

Mass: 150 kg

Duty cycle: 50%

Power: 71 W (average), 117 W (peak)

Thermal control by: Passive cooling and active temperature stabilization

Thermal operating range: 0 - 10° C

FOV: ±60° (along-track) × ±15° (cross-track)

Data rate: 3.3 Mbps (orbit average), 9.0 Mbps (peak)

Pointing requirements (spacecraft):
Control: 150 arcsec
Knowledge: 90 arcsec
Stability: 5 arcsec / 1 sec; 14 arcsec / 420 sec

Physical size: 50.0 × 35.5 × 38.7 cm

Technology. He joined the Jet Propulsion Laboratory as a National Research Council Resident Research Associate in 1978, and is currently an Element Leader in the Earth and Space Sciences Division. 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.

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For Further Information

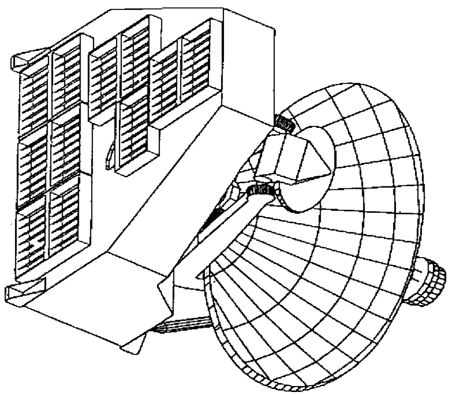
Diner, D.J., C.J. Bruegge, J.V. Martonchik, G.W. Bothwell, E.D. Danielson, E.L. Floyd, V.G. Ford, L.E. Hovland, K.L. Jones, and M.L. White, 1991: A Multi-angle Imaging SpectroRadiometer for terrestrial remote sensing from the Earth Observing System. *Int. J. of Imaging Systems and Technology*, **3**, 92-107.

MISR Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Level 1A Reformatted Annotated Product	3% :: 1% (@ equivalent reflectance of 1.0), 6% :: 2% (@0.05)	1 / (2 - 9 day)	275 m - 1.1 km :: Global; 275 m :: Regional	N / A :: Top of Atmosphere
Level 1B1 Radiometric Product	3% :: 1% (@ equivalent reflectance of 1.0), 6% :: 2% (@0.05)	1 / (2 - 9 day)	275 m - 1.1 km :: Global; 275 m :: Regional	N / A :: Top of Atmosphere
Level 1B2 Geo-rectified Radiance Product	3% :: 1% (@ equivalent reflectance of 1.0), 6% :: 2% (@0.05)	1 / (2 - 9 day)	275 m - 1.1 km :: Global; 275 m :: Regional	N / A :: Top of Atmosphere
Level 2 Top of Atmosphere/ Cloud Product	Parameter dependent	1 / (2 - 9 day)	1.1, 2.2, 17.6, 35.2 km :: Global	N / A :: Troposphere, Top of Atmosphere
Level 2 Aerosol/ Surface Product	Parameter dependent	1 / (2 - 9 day)	1.1, 17.6 km :: Global	N / A :: Troposphere, Surface
Level 3 Gridded Radiation Product	Parameter dependent	1 / (9 day, 16 day, month, season, year)	1.1, 2.2, 17.6, 35.2 km :: Global	N / A :: Surface Top of Atmosphere
Level 3 Gridded Cloud Product	Parameter dependent	1 / (9 day, 16 day, month, season, year)	1.1, 2.2, 17.6, 35.2 km :: Global	N / A :: Troposphere
Level 3 Gridded Aerosol Product	Parameter dependent	1 / (9 day, 16 day, month, season, year)	17.6 km :: Global	N / A :: Troposphere
Level 3 Gridded Surface Product	Parameter dependent	1 / month	1.1 km :: Global	N / A :: Surface
Level 1B2 Ancillary Geographic Product	Parameter dependent	Updated infrequently	1.1 km :: Global	N / A :: Surface
Level 1B2 Ancillary Radiometric Product	Parameter dependent	Updated 1 / month	N / A :: N / A	N / A :: N / A
Level 2 Aerosol Physical and Optical Properties Product	Parameter dependent	Updated infrequently	N / A :: N / A	N / A :: Atmosphere

MLS

MICROWAVE LIMB SOUNDER



Key MLS Facts

- Selected for flight on EOS CHEM series
- Heritage: UARS MLS
- Passive microwave limb-sounding radiometer / spectrometer
- Measures thermal emission from the atmospheric limb
- Spectral bands at millimeter and submillimeter wavelengths
- In-house Jet Propulsion Laboratory development; subsystems from industry

The scientific priorities and objectives of the MLS investigation are to study and monitor the following processes and parameters vital to global change research:

- Chemistry of the lower stratosphere and upper troposphere—MLS measures lower stratospheric temperature and concentrations of H_2O, O_3, ClO, HCl, OH, HNO_3, and N_2O, for their effects on (and diagnoses of) transformations of greenhouse gases, radiative forcing of climate change, and ozone depletion. MLS measures upper tropospheric H_2O and O_3 for their effects on radiative forcing of climate change and diagnoses of exchange between the troposphere and stratosphere.

- Chemistry of the middle and upper stratosphere—MLS monitors ozone chemistry by measuring radicals, reservoirs, and source gases in chemical cycles which destroy ozone.

- The effect of volcanoes on global change—MLS measures SO_2, and other gases mentioned above, in volcanic plumes to investigate the effects of volcanic injections into the atmosphere.

A very important contribution to the EOS Program is that MLS measurements are not degraded in regions containing ice clouds (including polar stratospheric clouds) or aerosols. This is significant because phenomena affecting global change, e.g., water vapor distribution near the tropopause and heterogeneous chemistry, occur in these regions.

Measurements are performed continuously, at all times of night and day, and can cover the altitude range from the upper troposphere to the lower thermosphere. The vertical scan is chosen to emphasize the lower stratosphere and upper troposphere, which are now of highest priority; however, the scan can be reprogrammed to emphasize other regions should priorities change. Complete latitude coverage is obtained each orbit. Pressure (from O_2 lines) and height (from a gyroscope measuring small changes in the field-of-view direction) are measured to provide accurate vertical information for the composition measurements.

The EOS version of this instrument continues the successful effort started on the Upper Atmosphere Research Satellite (UARS) MLS. The heterodyne radiometer systems used by MLS are capable of efficient measurement of atmospheric thermal emissions up to the frequencies of approximately 3 THz. Moreover, instrument modules can be easily changed (including additions and deletions) to accommodate evolving measurement priorities, resource availabilities, and technology advances. MLS contains heterodyne radiometers in four spectral bands:

- 200 GHz, which is primarily to continue the UARS MLS measurements of stratospheric O_3, ClO, and upper tropospheric water vapor;
- 300 GHz, which is primarily for water vapor and ozone from the upper troposphere through the stratosphere, stratospheric HNO_3, and pressure;
- 600 GHz, which is primarily for improved ClO measurements, and measurements of stratospheric HCl and N_2O; and
- 2.5 THz, which is primarily for OH.

Consideration is currently being given to an improved choice of spectral bands with the 300 GHz changed to a lower-cost 100 GHz, and to obtaining additional measurements from the 200 GHz and 2.5 THz bands. The MLS heterodyne radiometers have adequate sensitivity without requiring cooling.

Principal Investigator
Joe W. Waters

Dr. Waters has led the development of microwave limb sounding since its inception in 1974. His Ph.D. from the Massachusetts Institute of Technology (MIT) focused on microwave sensing of the upper atmosphere. Afterwards he was on the MIT research staff as a Co-Investigator on Nimbus microwave experiments. He moved on to the Jet

MLS Parameters

Instantaneous field-of-view at 640 GHz and higher frequencies: 1.5 km vertical × 3 km cross-track × 300 km along-track at the limb tangent point

Spectral bands: At millimeter and submillimeter wavelengths

Spatial resolution: 3 × 300 km horizontal x 1.2 km vertical

Mass: 600 kg

Duty cycle: 100%

Power: 588 W

Data rate: 100 kbps

Thermal control: Via radiators and louvres to space as well as heaters

Thermal operating range: 10 to 35° C

FOV: Boresight 60-70° relative to nadir

Instrument IFOV: ±2.5° (half-cone, along-track)

Pointing requirements (platform+instrument, 3σ):
Control: 36 arcsec
Knowledge: 1 arcsec per second
Stability: TBD
Jitter: TBD

Physical size: 130 × 180 × 170 cm (sensor with antenna); 170 × 50 × 50 cm (spectrometer)

Propulsion Laboratory (JPL) in 1973, and has been Principal Investigator on aircraft, balloon, and Upper Atmosphere Research Satellite (UARS) microwave limb sounding experiments. He is currently a senior research scientist at JPL, and supervisor for the Microwave Atmospheric Science and Upper Atmosphere Experiment Development groups.

Co-Investigators

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Jet Propulsion Laboratory

Lucien Froidevaux
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Robert S. Harwood
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Robert F. Jarnot
Jet Propulsion Laboratory

William G. Read
Jet Propulsion Laboratory

Peter H. Siegel
Jet Propulsion Laboratory

William J. Wilson
Jet Propulsion Laboratory

For Further Information

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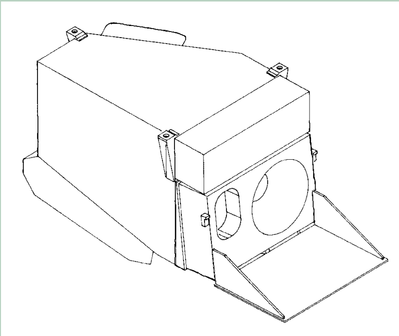
MLS Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Level-1 B Radiance, MLS	<3% :: <3%	2 / day (d,n)	1.3 x 2.5 deg :: 82N - 82S	2 km :: 0 - 80 km
Level-2 Data, MLS (Constituents, T, P, Geopotential Height)	Depends on Parameter	2 / day (d,n)	1.3 x 2.5 deg :: 82N - 82S	2 km :: 0 - 80 km

NOTE: These standard data products are preliminary pending peer review and agreement with the responsible EOS investigators

MODIS

MODERATE-RESOLUTION IMAGING SPECTRORADIOMETER



Key MODIS Facts

- Selected for flight on EOS AM and PM series
- Heritage: AVHRR, HIRS, LANDSAT TM, and NIMBUS-7 CZCS
- Medium-resolution, multi-spectral, cross-track scanning radiometer
- Measures biological and physical processes
- Phase C/D start August 1991
- Prime Contractor: Santa Barbara Research Center
- Responsible Center: NASA/Goddard Space Flight Center

MODIS is an EOS facility instrument designed to measure biological and physical processes on a global basis every 1 to 2 days. Slated for both the EOS AM and PM satellite series, the instrument will provide long-term observations from which to derive an enhanced knowledge of global dynamics and processes occurring on the surface of the Earth and in the lower atmosphere. This truly multidisciplinary instrument will yield simultaneous, congruent observations of high-priority atmospheric (cloud cover and associated properties), oceanic (sea surface temperature and chlorophyll), and land surface features (land cover changes, land surface temperature, and vegetation properties). The instrument is expected to make major contributions to understanding of the global Earth system, including interactions between land, ocean, and atmospheric processes.

The MODIS instrument employs a conventional imaging radiometer concept, consisting of a cross-track scan mirror and collecting optics, and a set of linear detector arrays with spectral interference filters located in four focal planes. The optical arrangement will provide imagery in 36 discrete bands between 0.4 and 14.5 µm selected for diagnostic significance in Earth science. The spectral bands will have spatial resolutions of 250 m, 500 m, or 1 km at nadir; signal-to-noise ratios of greater than 500 at 1-km resolution (at a solar zenith angle of 70°); and absolute irradiance accuracies of ±5% from 0.4 to 3 µm (2% relative to the sun) and 1 percent or better in the thermal infrared (3 to 14.5 µm). MODIS instruments will provide daylight reflection and day/night emission spectral imaging of any point on the Earth at least every 2 days, operating continuously.

MODIS will provide specific global data products, which include the following:

- Surface temperature with 1-km resolution, day and night, with absolute accuracy of 0.2 K for oceans and 1 K for land
- Ocean color, defined as ocean-leaving spectral radiance within 5 percent from 415 to 653 nm, enabled by atmospheric correction from near-infrared sensor channels

- Chlorophyll fluorescence within 50 percent at surface water concentrations of 0.5 mg/m^{-3}
- Concentration of chlorophyll_a within 35 percent
- Vegetation/land surface cover, conditions, and productivity
  - Net primary productivity, leaf area index, and intercepted photosynthetically active radiation
  - Land cover type, with change detection and identification
  - Vegetation indices corrected for atmosphere, soil, and directional effects
  - Snow cover and reflectance
- Cloud cover with 250-m resolution by day and 1,000-m resolution at night
- Cloud properties characterized by cloud droplet phase, optical thickness, droplet size, cloud-top pressure, and emissivity
- Aerosol properties defined as optical thickness, particle size, and mass transport
- Fire occurrence, size, and temperature
- Global distribution of total precipitable water
- Cirrus cloud cover.

MODIS will fly on both the EOS AM and PM satellites to maximize cloud-free remote sensing of the Earth's surface and to exploit synergism with other EOS sensors.

Team Leader
Vincent Salomonson

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 8 years. He also served for 12 years 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

MODIS Parameters

36 spectral bands—21 within 0.4-3.0 µm; 15 within 3-14.5 µm

Continuous global coverage every 1 to 2 days

Polarization sensitivity is less than 2% out to 2.2 µm

Signal-to-noise ratio 838:1 (443 nm), 754:1 (531 nm), and 516:1 (869 nm) at 70° solar zenith angle

Absolute irradiance accuracy of 5% for <3 µm and 1% for >3 µm

Daylight reflection and day/night emission spectral imaging

Swath: 2,300 km at 110° (±55°)

Mass: 225 kg

Duty cycle: 100%

Power: 175 W (average), 225 W (peak)

Data rate: 6.2 Mbps (average), 10.6 Mbps (day), 3.2 Mbps (night)

Thermal control by: Radiator

Thermal operating range: 283 K ±12 K

Instrument IFOV: 250 m (2 bands), 500 m (5 bands), 1,000 m (29 bands)

Pointing requirements (platform+instrument, 3σ):
Control: 3,600 arcsec
Knowledge: 141 arcsec
Stability: 28 arcsec/sec
Jitter: 1,031 arcsec/sec (yaw and roll), 47 arcsec/sec (pitch)

Physical size: 95.2 × 158.3 × 133.6 cm (stowed)

Investigator Team. Additional experience includes over 20 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 120 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 10 NASA awards for exceptional scientific achievement, service, and performance; the Distinguished Achievement Award of the IEEE Geoscience and Remote Sensing Society; the William T. Pecora Award; and the Distinguished Alumnus Award from Colorado State University. In addition to his present duties as Director of Earth Sciences at Goddard, he served as the President of the American Society for Photogrammetry and Remote Sensing (ASPRS) in 1992. He was made a Fellow of ASPRS in 1994.

Science Team Members

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Zhengming Wan,
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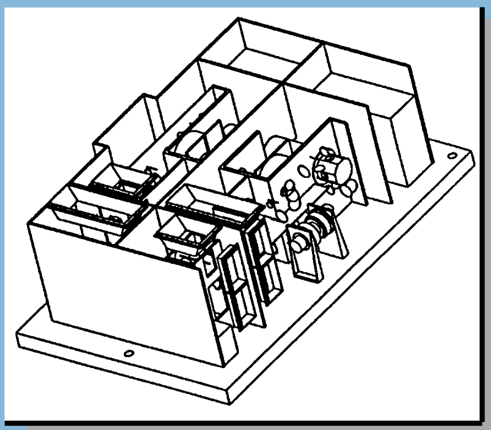
MODIS Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Level-1 A Radiance			0.25, 0.5, 1 km :: Global	
Level-1B Radiance, Calibrated Geolocated	5% (1σ) :: RMS<NEΔL	1 / day	0.25, 0.5, 1 km :: Global	N / A :: N / A
Aerosol Product		1 / day	50 km (Land), 5 km (Ocean) :: Global	N / A :: Atmosphere
Cloud Product		1-2 / day	5, 50 km :: Global	N / A :: Cloud
Surface Reflectance		1-9 / day	1 km :: Land	N / A :: Surface
Snow Cover	10% ::	1 / day	1 km :: Land	N / A :: Surface
Land-surface Temperature/ Emissivity		1 / day, 1 / week, 1 / month	1 km :: Land / Regional	N / A :: Surface
Land-cover Type	10% ::	1 / (3 months)	1 km :: Land	N / A :: Surface
Chlorophyll_a Pigment Concentration	30%-60% (Case1), 50% (Case II) ::	1 / day, 1 / week, 1 / month	1 km :: Ocean-I & II / Regional, Local	N / A
Water-leaving Radiance	0.0015 ::	1 / day, 1 / week, 1 / month	1 km :: Local	N / A :: Surface
PAR	5-10% ::	1 / day (d)	1 km :: Ocean / Global	N / A :: Surface, Atmosphere
Sea-Surface Temperature (SST)	0.3-0.5 K ::	1 / day, 1 / week, 1 / month	1 km :: Ocean / Local	N / A :: Surface
Cloud Mask		2 / day	250 m, 1 km :: Global	N / A :: Cloud

MOPITT

Measurements of Pollution in the Troposphere



Key MOPITT Facts

- Selected for flight on EOS AM-1
- Heritage: Pressure-modulated cell elements used in the PMR, SAMS, and ISAMS instruments, using similar correlation spectroscopy techniques
- Four-channel correlation spectrometer with cross-track scanning
- Flight on EOS AM-2 to be confirmed
- Canadian Space Agency to provide the instrument
- Prime Contractor: COM DEV Atlantic

The MOPITT experiment is provided under a Memorandum of Understanding with the Canadian Space Agency (CSA). MOPITT will measure emitted and reflected infrared radiance in the atmospheric column which, when analyzed, permits retrieval of tropospheric CO profiles and total column CH_4.

Both CO and CH_4 are produced by biomass systems, oceans, and human activities. CO is intimately connected with the OH chemical cycle in the troposphere, and moves both vertically and horizontally within the troposphere. CH_4 is a greenhouse gas and is increasing on an annual basis. MOPITT measurements will permit studies of the global and temporal distributions that drive budget and source/sink studies. Since the human species has a significant influence on both CO and CH_4 concentrations, a better understanding of the role of these constituents is essential in understanding anthropogenic effects on the environment.

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

Atmospheric sounding and column CO are mapped by using thermal and reflected solar channels in the regions of 4.7 and 2.3 µm, respectively. Column CO and CH_4 are measured using solar channels viewed through modulation cells to sense solar radiation reflected from the surface. The solar channels are duplicated in the instrument at different correlation cell pressures, to allow a failure in one channel without compromising the column measurement.

MOPITT is designed as a scanning instrument. It has a field-of-view of 1.8°, which is equivalent to an approximately 22-km footprint at nadir. The instrument line consists of 29 pixels, each at 1.8° increments. The maximum scan angle is 26.1° off-axis, which is equivalent to a swath width of 640 km. This swath leaves gaps in coverage between successive orbits using the nominal 705-km altitude and 98.2° inclination orbit.

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

Principal Investigator
James Drummond

James Drummond has taught in the Physics Department at the University of Toronto since 1979, as Professor since 1992. He studied at Oxford University where he obtained his B.A. and D.Phil. degrees in Physics. He was a Visiting Scientist in the Atmospheric Chemistry Division of the National Center for Atmospheric Research in 1987. His research interests are in the field of atmospheric measurements and modeling, and he has participated in several balloon and spacecraft experiments in these areas. Dr. Drummond has presented research papers at international meetings and symposia, and in refereed journals.

MOPITT Parameters

Correlation spectroscopy utilizing both pressure- and length-modulated gas cells, with detectors at 2.3, 2.4, and 4.7 µm

Uses pressure modulation and length modulation cells to obtain CO concentrations in 3-km layers and CH_4 column

CO concentration accuracy is 10%

CH_4 column abundance accuracy is 1%

Swath: 616 km

Spatial resolution: 22 × 22 km

Mass: 182 kg

Power: 243 W (average), 250 W (peak)

Duty cycle: 100%

Data rate: 25 kbps

Thermal control by: 80 K Stirling cycle cooler, capillary pumped coldplate and passive radiation

Thermal operating range:
25° C (instrument), 100 K (detectors)

FOV: 22 × 638 km (scanned, 29 fields)

Instrument IFOV: 22 × 22 km (1.8° × 1.8°)

Pointing requirements (platform+instrument, 3σ):
Control: 500 arcsec
Knowledge: 300 arcsec
Stability: 322 arcsec/12.47 sec

Physical size:
103 × 73 × 44 cm (stowed),
103 × 75 × 44 cm (deployed)

Co-Investigators

Guy Brasseur
National Center for Atmospheric Research

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Jack McConnell
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Henry G. Reichle
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N. Roulet
McGill University, Canada

For Further Information

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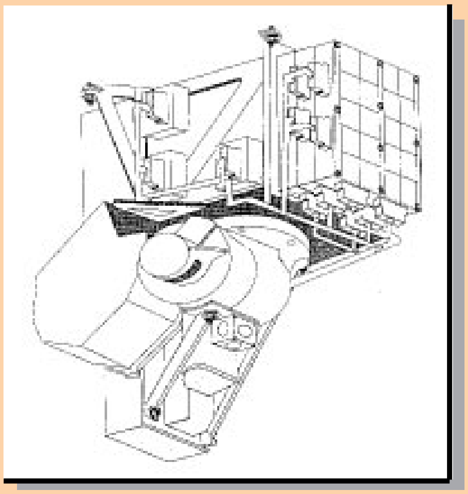
MOPITT Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Level-1B Radiance (= Ancillary Data including CR Pressure)		1 view / 0.4 seconds	22 km :: Global	:: Atmosphere
CH_4 Column (Total Burden)	1% :: 1%	1 view / 0.4 seconds	22 km :: Global	Column :: Atmosphere
CO Profiles	10% :: 10%	1 view / 0.4 seconds	22 km :: Global	4 km :: 0-15 km
CO Column (Total Burden)	10% :: 10%	1 view / 0.4 seconds	22 km :: Global	Column :: Atmosphere

ODUS

Ozone Dynamics Ultraviolet Spectrometer



Key ODUS Facts

- Selected for flight on EOS CHEM series
- Heritage: EXOS-C BUV, Nimbus 7 SBUV/TOMS, EP/ADEOS TOMS
- Nadir-viewing ultraviolet grating spectrometer
- Global mapping of total column ozone
- Mapping of volcanic SO_2
- Mapping of total column NO_2 in urban polluted air
- 10 km × 10 km IFOV
- EOS Facility Instrument provided by National Space Development Agency of Japan to NASA

ODUS will be a Facility Instrument provided by NASDA to NASA in exchange for the flight of the SeaWinds instrument on ADEOS-2. Similar to the NASA TOMS instruments, the ODUS instrument will provide daily global measurements of total column ozone. The ODUS instrument will have additional wavelengths in the near-ultraviolet to measure total column NO_2. It will measure Earth's backscattered ultraviolet radiation in 10 wavelength bands (306-410 nm).

Science Objectives:

- Continue to monitor total column ozone for the detection of long-term changes in ozone.
- Use the total ozone fields as a tracer of upper atmospheric winds.
- Combine the ODUS total ozone data with measurements from the stratospheric ozone-profiling instruments on EOS CHEM to infer tropospheric ozone.
- Use total column NO_2 measurements to determine the extent of denitrification in the wintertime polar vortex.
- Measure SO_2 emitted from volcanic eruptions.
- Measure SO_2 emitted from anthropogenic sources.

Team Leader
To be determined

The ODUS mission is a collaborative effort between NASA and NASDA, with the details of the partnership currently being negotiated. NASA will select the U.S. Team Leader and science team members through a competitive peer review process, evaluating the merit of U.S. proposals to use data from these instruments to address key issues in global climate change. NASDA will identify the French scientists who will participate as team members and the individual to serve as the French Team Leader.

Team Members

To be determined

ODUS Parameters

The following information is preliminary:

Inflight calibration: Multiple diffuser plates, Hg lamp for wavelength calibration

Mass: 40 kg

Power: 70 W

Duty cycle: 50% (measurement on sunlit side of orbit)

Data rate: 50 kbps (12 bits A/D) + ancillary data

Thermal control: Heaters and radiators

Instrument IFOV: $1.6° \times 1.6°$

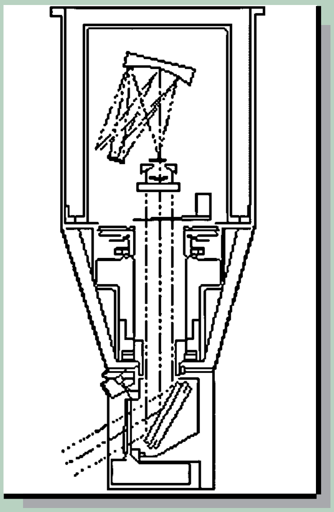
FOV: along track: 1.6° centered at nadir, across track: 120° centered at nadir

Pointing requirements (Platform+instrument 3σ):
Control: 1800 arcsec
Knowledge: 900 arcsec
Stability: TBD
Jitter: TBD

Spectral coverage in 10 bands from 306 nm to 410 nm with 0.5 nm resolution

SAGE III

STRATOSPHERIC AEROSOL AND GAS EXPERIMENT III



Key SAGE III Facts

- Selected for flight on Meteor 3M and International Space Station
- Heritage: SAM II, SAGE I and SAGE II
- Earth limb-scanning grating spectroradiometer
- Phase C/D start November 1994
- First flight aboard Russian Meteor 3M in 1998
- Prime Contractor: Ball Aerospace
- Responsible Center: NASA/Langley Research Center

SAGE III is an improved extension of the successful Stratospheric Aerosol Measurement II (SAM II), SAGE I, and SAGE II experiments. The additional wavelengths and operation during both lunar and solar occultation that SAGE III provides will improve aerosol characterization; improve the gaseous retrievals of O_3, H_2O, and NO_2; add retrievals of NO_3 and OClO; extend the vertical range of measurements; provide a self-calibrating instrument independent of any external data needed for retrieval; and expand the sampling coverage. The instrument team will accomplish the following science objectives:

- Retrieve global profiles (with 1- to 2-km vertical resolution) of atmospheric aerosols, ozone, water vapor, NO_2, NO_3, OClO, temperature, and pressure in the mesosphere, stratosphere, and troposphere
- Investigate the spatial and temporal variability of the measured species in order to determine their role in climatological processes, biogeochemical cycles, the hydrologic cycle, and atmospheric chemistry
- Characterize tropospheric and stratospheric aerosols and upper tropospheric and stratospheric clouds, and investigate their effects on the Earth's environment, including radiative, microphysical, and chemical interactions
- Extend the SAM II, SAGE I, and SAGE II self-calibrating solar occultation data sets (begun in 1978), enabling the detection of long-term trends
- Provide atmospheric data essential for the calibration and interpretation/correction of other satellite sensors, including EOS- and ground-based sensors.

SAGE III takes advantage of both solar and lunar occultations to measure aerosol and gaseous constituents of the atmosphere. Most of the objectives rely on the solar occultation technique, which involves measuring the effects of extinction of solar energy by aerosol and gaseous constituents in the spectral region from 0.29 to 1.55 µm during spacecraft sunrise and sunset events. For example, during a sunset event, exoatmospheric solar limb data are obtained when the sun-satellite vector is high above the Earth's atmosphere. As the sun sets, a series of scans through the atmosphere is performed during which measurements of the solar transmission through the atmosphere are made. Because all atmospheric measurements are ratioed to the exoatmospheric solar limb profiles taken during the same event, the instrument is self-calibrating, and the retrieved data are not susceptible to long-term instrument degradation.

The moon will be used as another source of light for occultation measurements. In the spectral region from 0.4 to 0.95 µm, the moon has a relatively flat, i.e., grey, albedo. A determination of the average lunar spectral albedo is obtained by ratioing the exoatmospheric scans of the moon to an appropriate set of exoatmospheric scans of the sun, thereby ratioing out the structure in the solar spectrum. This average lunar spectral albedo can then be used along with the extinction cross sections of all absorbing species in an optimal fit to the measurements.

Present plans call for concurrent flight of at least two instruments—one in an inclined orbit (51.6°) and one in a sun-synchronous orbit (~9:15 a.m.)—to obtain near-global coverage. This comprehensive approach will allow SAGE III to make long-term measurements and to provide the congruent aerosol and cloud data important to radiative and atmospheric chemistry studies.

Principal Investigator
M. Patrick McCormick

M. Patrick McCormick received an M.A. and Ph.D. in Physics from the College of William & Mary. He has been with NASA/Langley Research Center since 1967, and is now Head of the Aerosol Research Branch. Dr. McCormick is Principal Investigator of the SAM II, SAGE I, SAGE II, SAGE III, and LITE spaceflight experiments, as well as numerous other atmospheric remote-sensing instrument and data analysis experiments. He received the Arthur S. Flemming Award for Outstanding Young People in Federal Service in 1979, the NASA Exceptional Scientific Achievement Medal in 1981, the American Meteorological Society's Jule G.

SAGE III Parameters

Self-calibrating solar and lunar occultation, with measurements within nine spectral regions between (290-1,550 nm), to study aerosols, ozone, OClO, NO_2, NO_3, water vapor, temperature, and pressure

Swath: n/a (looks at sun and/or moon through Earth's limb)

Spatial resolution: 1-2 km vertical

Mass: 40 kg excluding unique hardware

Duty cycle: During solar and lunar Earth occultation

Power: 30 W (average), 75 W (peak)

Data rate: 100 kbps for 8 min, three times per orbit

Thermal control by: Passive, heaters, and thermal electric cooler

Thermal operating range: 10-30° C

FOV: ±185° azimuth, 13-31° elevation, dependent on orbital altitude

Instrument IFOV: <0.5 km vertical at 20-km tangent height

Pointing requirements (platform+instrument, 3σ):
Control: 1°
Knowledge: 0.25°/axis
Stability: 30 arcsec/sec per axis

Physical size: 25 × 25 × 42 cm
34-cm diameter × 74 cm

Charney Award in 1991, and numerous NASA Group or Special Achievement Awards. In addition, he received an Honorary Doctor of Science degree from Washington & Jefferson College in 1981, and has served on their Board of Trustees. Dr. McCormick is a member of the International Radiation Commission, the American Meteorological Society, and the American Geophysical Union, and chairs the International Coordination Group on Laser Atmospheric Studies. He is also a member of the National Academy of Sciences Panel on Aerosol Radiative Forcing, and the Committee on Meteorological Analysis, Prediction, and Research.

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Gabor Vali
University of Wyoming

Steven C. Wofsy
Harvard University

Joseph M. Zawodny
NASA/Langley Research Center

Two Russian scientists will be added

For Further Information

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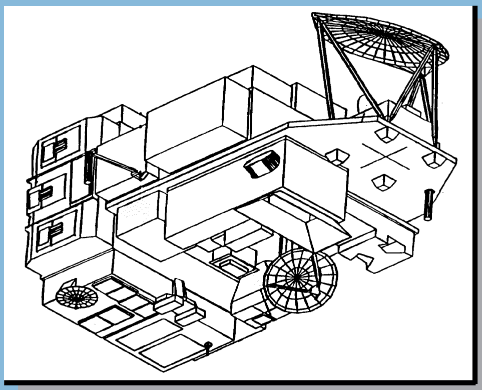
SAGE III Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Level-1 B Transmission Profiles (65 wave lengths), Solar SAGE-III	0.05% :: 0.05%	1 / (2 minutes), 30 / day	200 x 2.5 km :: Global	1 km :: 0-100 km
Aerosol Extinction Profiles (at 7 wavelengths)	5% :: 5%	1 / (2 minutes), 30 / day	<2 x <1 deg :: Global	1 km :: 0-40 km
Cloud Height, Top	0.2 km :: 5%	1 / (2 minutes), 30 / day	<2 x <1 deg :: Global	0.5 km :: Stratosphere / Troposphere
H_2O Conc & Mixing Ratio	10% :: 15%	1 / (2 minutes), 30 / day	<2 x <1 deg :: Global	1 km :: 3-50 km
NO_2 Conc. & Mixing Ratio	10% :: 15%	1 / (2 minutes), 30 / day	<2 x <1 deg :: Global	1 km :: 10-50 km
NO_3 Conc. & Mixing Ratio, Lunar	10% :: 10%	1 / (2 minutes), 30 / day (n)	<2 x <1 deg :: Global	1 km :: 20-55 km
O_3 Conc. & Mixing Ratio	6% :: 5%	1 / (2 minutes), 30 / day	<2 x <1 deg :: Global	1 km :: 6-85 km
OClO Conc. & Mixing Ratio, Lunar	20% :: 20%	1 / (2 minutes), 30 / day	<2 x <1 deg :: Global	3 km :: 15-25 km
Pressure	2% :: 2%	1 / (2 minutes), 30 / day	<2 x <1 deg :: Global	1 km :: 6-70 km
Temperature Profile	2 K :: 2 K	1 / (2 minutes), 30 / day	<2 x <1 deg :: Global	1 km :: 6-70 km

NOTE: These standard data products are preliminary pending peer review and agreement with the responsible EOS investigators

SeaWinds



Key SeaWinds Facts

- Selected for flight on ADEOS II
- Heritage: SEASAT, NSCAT.
- KuBand Scatterometer with rotating antenna used to determine global radar scattering cross section and infer wind velocity over the ocean.
- Acquires all-weather measurements of surface wind speed and direction over the global oceans.
- Continues cooperative efforts between the U.S. and Japan to evaluate and monitor global change
- Follow-on to NSCAT, which will fly on ADEOS in 1996
- In-house Jet Propulsion Laboratory development, with subcontracts for major subsystems
- Phase C/D started in 1992
- Requires spatially and temporally co-located multi-channel microwave radiometer measurements for atmospheric attenuation correction

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

SeaWinds transmits pulses of microwave radiation at 13.4 GHz and measures the backscattered signal from the ocean. With knowledge of the range and instrument parameters such as antenna gain, the backscattered power data can be used to directly calculate the normalized radar cross section of the sea surface. At moderate incidence angles, the received power is primarily a result of Bragg scattering from centimetric ocean waves whose amplitudes and directional distributions are in approximate local equilibrium with the local wind; thus, the backscattered power will vary as a function of wind speed and wind direction relative to the radar beam. An empirically based geophysical model function relates the normalized radar cross section to wind speed and relative direction as a function of incidence angle, polarization, and frequency of the incident and backscattered radiation. Multiple measurements of the normalized radar cross section of the same area on the sea surface, but from different directions relative to the wind, are used to invert the model function to derive both wind speed and wind direction simultaneously.

NASA's SeaWinds scatterometer will provide high-accuracy wind speed and direction measurements over at least 90% of the ice-free global oceans every 2 days. SeaWinds will provide a continuing set of long-term wind data for studies of ocean circulation, climate, air-sea interaction, and weather forecasting. SeaWinds is a follow-on to the NASA Scatterometer (NSCAT), which will be launched in 1996 onboard NASDA's Advanced Earth Observation Satellite (ADEOS) and will also provide measurements of ocean surface winds in clear sky and cloudy conditions. Since approximately two-thirds of the Earth's surface is covered by oceans, data from SeaWinds will play a crucial role in interdisciplinary scientific investigations of the global weather patterns, climate systems, and wind-driven ocean circulation.

The SeaWinds instrument is a specialized microwave radar designed specifically to measure winds over the oceans. The SeaWinds mission will operate for 3 years after launch and has a 5-year goal. In a major change to allow accomodation on the ADEOS-II spacecraft, SeaWinds will use a 1-meter-diameter dish antenna with 2 beams in place of NSCAT's array of 6, 3-m-long antennas. The dish antenna is rotated about the satellite nadir axis at 18 rpm. SeaWinds radiates and receives microwave pulses at a frequency of 13.4 GHz across broad regions of the Earth's surface. SeaWinds will collect data in a continuous, 1800-km-wide band centered on the subsatellite track.

SeaWinds data products will consist of global multi-azimuth normalized radar cross section measurements and 50-km-resolution ocean vector winds (~12% speed and 20° direction accuracies for wind speeds of 3-30 m/sec) in the measurement swath.

Principal Investigator
Michael Freilich

Michael Freilich received degrees in Physics (honors) and Chemistry from Haverford College, and a Ph.D. in Oceanography from Scripps Institution of Oceanography in 1982. From 1982-83, he was an assistant professor at the Marine Sciences Research Center at the State University of New York. He joined the Jet Propulsion Laboratory in 1983, as a member of the Oceanography Group studying scatterometry and surface wave dynamics. Currently, he is an associate professor in the School of Oceanic and Atmospheric Sciences at Oregon State University. In addition, he is a Principal Investigator and Coordinating Investigator on the European Space Agency (ESA) European Remote Sensing Satellite (ERS-1/2) Science Working Team and was previously Project Scientist for the NSCAT Project.

SeaWinds Parameters

Active microwave radar at 13.402 GHz

Wind speeds between 3-30 m sec^{-1} accurate to 12%

Wind vector directions accurate to 20°

Swath: One 1800 km swath

Spatial resolution: 50 km

Mass: 250 kg

Power: 275 W

Duty cycle: 100%

Data rate: 20 kbps

Thermal control by: self

Thermal operating range: 5-40° C

FOV: Rotating (at 18 rpm) pencilbeam antenna with dual feeds pointing at 40° and 46° from nadir

IFOV: ±52° from nadir

Pointing requirements (3σ):
Control: <0.3° (~1000 arcsec)
Knowledge: <0.15° (~500 arcsec)
Stability: <0.008°/sec (30 arcsec/sec)

Physical Size:
32 × 46 × 24 cm
81 × 86 × 56 cm
100 cm diameter antenna dish on top of 60 cm diameter × 120 cm pedestal

Co-Investigators

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University of Washington

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University of Rhode Island

David Halpern
Jet Propulsion Laboratory

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For Further Information

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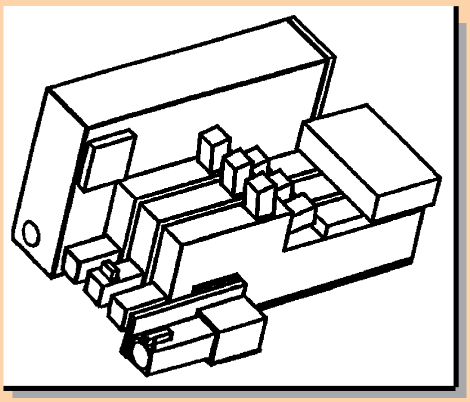
SeaWinds Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Level-1B Product			50 km :: Global	
Global Backscatter Cross-section	— :: 0.25 dB	Global coverage every 2 days	50 km :: Global (Land, Ocean, & Ice)	N / A :: Surface
Ocean Vector Winds	10-12% speed :: — 20° direction :: —	90% oceans every 2 days	50 km :: Ocean	N / A :: Surface

SOLSTICE

Solar Stellar Irradiance Comparison Experiment



Key SOLSTICE Facts

- Selected for flight of opportunity
- Heritage: UARS SOLSTICE
- Four channel ultraviolet spectrometer (two-axis solar track)
- Composed of an ultra-high-resolution spectrometer, low-resolution spectrometers, and an extreme ultraviolet photometer
- Provides daily measurement of full-disk solar ultraviolet irradiance, with calibration maintained by comparison to bright, early-type stars
- Responsible Center: National Center for Atmospheric Research

SOLSTICE provides precise daily measurements of the full-disk solar ultraviolet (UV) irradiance between 5 and 440 nm. The sun's UV radiation is the dominant energy source for the Earth's atmosphere, where small changes in the radiation field have an important effect on atmospheric temperature, chemistry, structure, and dynamics. Moreover, even small alterations in the atmosphere, e.g., small changes in total ozone, can produce dramatic differences in the solar radiation reaching the Earth's surface. Measuring small changes in solar UV irradiance will improve understanding of corresponding changes in the photochemistry, dynamics, and energy balance of the middle atmosphere. Changes resulting from the 27-day solar rotation and the 11-year solar cycle will receive emphasis, as will those arising from solar flare incidents. SOLSTICE will continue the UV observations initiated by its predecessor aboard the Upper Atmosphere Research Satellite (UARS).

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

The investigation will also model the penetration of solar radiation down into the Earth's atmosphere and establish the radiation field at all locations and altitudes, including the Earth's surface. In certain wavelength intervals, the depth of penetration varies dramatically due to details in the atmospheric absorption, and calculations require solar data with very high spectral resolution. To accommodate these measurements, a separate, high-resolution spectrometer channel is included. The standard SOLSTICE data product will be a daily average of the solar UV irradiance from 5 to 440 nm. More specifically, data products will consist of solar UV irradiance from 115 to 440 nm, the solar UV irradiance from 115 to 320 nm at much higher resolution, and extreme UV irradiance between 5 and 20 nm.

Principal Investigator
Gary Rottman

Gary Rottman, who holds an M.S. and Ph.D. in Physics from Johns Hopkins University, has spent most of his professional career at the University of Colorado; however, he presently serves as Senior Scientist at the High-Altitude Observatory of the National Center for Atmospheric Research. His space research includes roles as Principal or Co-Investigator on numerous solar and atmospheric investigations, including Solar-Mesosphere Explorer, the Upper Atmosphere Research Satellite (UARS) SOLSTICE Program, and solar extreme ultraviolet Spartan and rocket programs.

Co-Investigators

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George M. Lawrence
University of Colorado

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University of Colorado

Raymond G. Roble
National Center for Atmospheric Research

Paul C. Simon
Belgian Institute of Space Aeronomy

Tom N. Woods
National Center for Atmospheric Research

SOLSTICE Parameters

Spectral range from 5-440 nm

Photometric accuracy better than 5% absolute (1% relative)

Spectral resolution: 0.2 nm and 0.0015 nm

Swath: n/a

Spatial resolution: n/a

Mass: 99.5 kg

Duty cycle: 74% data taking

Power: 34 W (99% of time), 42 W (1% of time)

Data rate: 5 kbps (average), 8 kbps (peak)

Thermal control by: Passive radiator

Thermal operating range: 0-30° C (15° average)

FOV: 1.5°

Instrument IFOV: n/a

Pointing requirements:
Control: ±6 arcmin
Knowledge: 20 arcsec
Stability: 15 arcsec per 15 min
Jitter: 15 arcsec per sec

Physical size: 121 × 88 × 61 cm

Rottman, G.J., T.N. Woods, and T.P. Sparn, 1993: Solar Stellar Irradiance Comparison Experiment I: 1 Instrument Design and Operation. *J. Geophys. Res.*, **98**, 10,667-10,677.

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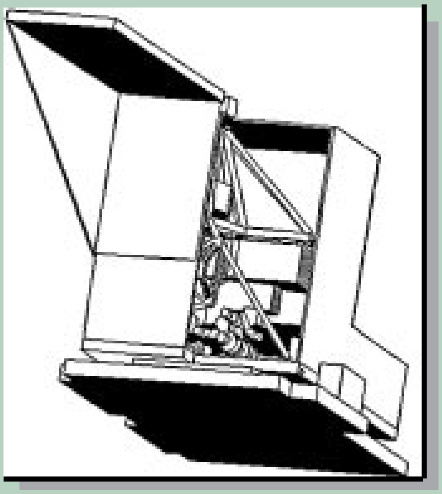
SOLSTICE Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Level-1 B Radiance	10% :: N/A	4/day	2 deg :: Global	1 km :: 0 - 100 km
Solar UV Irradiance, (1 nm res.)	3-5% :: 1%	1/hour	N/A :: N/A	N/A :: N/A

NOTE: These standard data products are preliminary pending peer review and agreement with the responsible EOS investigators

TES

Tropospheric Emission Spectrometer



Key TES Facts

- Selected for flight on EOS CHEM series
- Heritage: ATMOS, SCRIBE, AES
- High-spectral-resolution infrared imaging Fourier transform spectrometer
- Generates three-dimensional profiles on a global scale of virtually all infrared-active species from Earth's surface to the lower stratosphere
- In-house Jet Propulsion Laboratory development

TES is a high-resolution infrared imaging Fourier transform spectrometer with spectral coverage of 2.3 to 15.4 µm at a spectral resolution of 0.025 cm^{-1}, thus offering line-width-limited discrimination of essentially all radiatively active molecular species in the Earth's lower atmosphere. TES has the capability to make both limb and nadir observations. In the limb mode, TES has a height resolution of 2.3 km, with coverage from 0 to 32 km. In the down-looking modes, TES has a spatial resolution of 50 × 5 km (global) or 5 × 0.5 km (local), with a swath of 50 × 90 km (global) or 5 × 9 km (local). TES is a pointable instrument and can access any target within 45° of the local vertical, or produce regional transects up to 1,700 km length without any gaps in coverage.

TES employs both the natural thermal emission of the surface and atmosphere and reflected sunlight, thereby providing day-night coverage anywhere on the globe.

Observations from TES will further understanding of long-term variations in the quantity, distribution, and mixing of minor gases in the troposphere, including sources, sinks, troposphere-stratosphere exchange, and the resulting effects on climate and the biosphere. TES will provide global maps of tropospheric ozone and its photochemical precursors. These observations will serve as primary inputs to a database of the three-dimensional distribution (on global, regional, and local scales) of gases important to tropospheric chemistry, troposphere-biosphere interactions, and troposphere-stratosphere exchange. Other objectives include:

- Simultaneous measurements of NO_y, CO, O_3, and H_2O for use in the determination of the global distribution of OH, an oxidant of central importance in tropospheric chemistry
- Measurements of SO_2 and NO_y as precursors to the strong acids H_2SO_4 and HNO_3, which are the main contributors to acid deposition
- Measurements of gradients of many tropospheric species in order to understand troposphere-stratosphere exchange

- Determination of long-term trends in radiatively active minor constituents in the lower atmosphere to investigate effects on global radiative balance and atmospheric dynamics.

TES measurements will help determine local atmospheric temperature and humidity profiles, local surface temperatures, and local surface reflectance and emittance. TES observations will also be used to study volcanic emissions for hazard mitigation, indications of the chemical state of the magma, eruption prediction, and quantification of the role of volcanoes as sources of atmospheric aerosols.

The aforementioned database will calibrate models of the present and future state of the Earth's lower atmosphere. These models will investigate topics such as:

- Biogeochemical cycles between the lower atmosphere and biosphere (primarily carbon monoxide and methane)
- Global climate modification caused by an increase in radiatively active gases
- Distribution and lifetimes of chlorofluorocarbons (CFCs) and halons, which contribute substantially to the depletion of stratospheric ozone
- Changes in the oxidizing power of the troposphere and the distribution of tropospheric ozone caused by urban and regional pollution sources, particularly carbon monoxide, nitrogen oxides, methane, and other hydrocarbons
- Acid deposition precursors
- Sources and sinks of species important to the generation of tropospheric and stratospheric aerosols
- Natural sources of trace gases such as methane from organic decay, nitrogen oxides from lightning, and sulphur compounds from volcanoes.

Principal Investigator
Reinhard Beer

Dr. Beer received a B.Sc. and Ph.D. in Physics from the University of Manchester, United Kingdom. He has been associated with the Jet Propulsion Laboratory since 1963; his current

TES Parameters

Maximum sampling time of 8 sec, with a signal-to-noise ratio of up to 600:1

Limb mode: Height resolution = 2-3 km, height coverage = 0-33 km

Nadir and limb viewing (fully targetable)

Spectral region 2.3 to 15.4 µm, with four single-line arrays optimized for different spectral regions

Swath: n/a

Spatial resolution: 0.75 × 7.5 mrad (narrow angle), 7.5 × 75 mrad (wide angle)

Mass: 300 kg

Duty cycle: Variable

Power: 300 W (average)

Data rate: <12.2 Mbps (peak)

Thermal control by: Stirling cycle cooler, heater, central thermal bus, radiator

Thermal operating range: 0-30° C

FOV: +45° to -71° along-track, ±45° cross-track

Instrument IFOV: 12 × 7.5 mrad (narrow angle), 120 × 75 mrad (wide angle)

Pointing requirements (platform+instrument, 3σ):
Control: 108 arcsec
Knowledge: 108 arcsec
Stability: 36 arcsec/sec
Jitter: TBD

Physical size: 140 × 130 × 100 cm (stowed); 220 × 130 × 100 cm (deployed)

position is that of Senior Research Scientist and Supervisor of the Tropospheric Science Group, and Earth and Space Sciences Division. Dr. Beer was chairman of the NASA Infrared Experiments Working Group and now serves as Principal Investigator for the Airborne Emission Spectrometer (AES) as well as Co-Investigator on the Atmospheric Laboratory for Applications and Science (ATLAS) Atmospheric Trace Molecules Observed by Spectroscopy (ATMOS) experiment. He has been awarded the NASA Exceptional Scientific Achievement Medal for the discovery of extraterrestrial deuterium, three NASA group achievement awards, and numerous certificates of recognition.

Co-Investigators

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For Further Information

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TES Data Products

PRODUCT NAME	ACCURACY Absolute :: Relative	TEMPORAL RESOLUTION	HORIZONTAL Resolution :: Coverage	VERTICAL Resolution :: Coverage
Level-1B Radiance, TES (IR spectra in selected bands 2.3-15.4 μm)	1% :: 1%	1/(16 day) measured over a 4-day period	53 x 169 km :: Global	
CH_4 Mixing Ratio	:: 14-40 ppbv	1/(16 day) measured over a 4-day period	53 x 169 km :: Global	2-6 km :: 0-33 km
CO Mixing Ratio	:: 3-15 ppbv	1/(16 day) measured over a 4-day period	53 x 169 km :: Global	2-6 km :: 0-33 km
HNO_3 Mixing Ratio	:: 3 pptv	1/(16 day) measured over a 4-day period	53 x 169 km :: Global	2-3 km :: 0-33 km
N_2O Mixing Ratio	:: 0.01-20 ppbv	1/(16 day) measured over a 4-day period	53 x 169 km :: Global	2-6 km :: 0-33 km
NO Mixing Ratio	:: 15-25 pptv	1/(16 day) measured over a 4-day period	53 x 169 km :: Global	2-3 km :: 0-33 km
NO_2 Mixing Ratio	:: 500 pptv	1/(16 day) measured over a 4-day period	53 x 169 km :: Global	2-3 km :: 0-33 km
O_3 Mixing Ratio	:: 3-20 ppbv	1/(16 day) measured over a 4-day period	53 x 169 km :: Global	2-6 km :: 0-33 km
Temperature Profile	2 K :: 0.2 K	1/(16 day) measured over a 4-day period	53 x 169 km :: Global	4-6 km :: 0-33 km
H_2O/HDO Mixing Ratio	:: 0.5-50 ppmv	1/(16 day) measured over a 4-day period	53 x 169 km :: Global	2-6 km :: 0-33 km
Land-Surface Brightness Temperature	1 K :: 0.1 K	1/(16 day) measured over a 4-day period	53 x 169 km :: Global	N/A :: Surface
Level 2 Detection Flags			53 x 169 km :: Global	

NOTE: These standard data products are preliminary pending peer review and agreement with the responsible EOS investigators

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Interdisciplinary Science Investigations

Interdisciplinary Science Investigations

Mark Abbott

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Peter G. Brewer

Josef Cihlar

Robert Dickinson

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John S. Godfrey

Barry E. Goodison

William Grose

James Hansen

Dennis L. Hartmann

Bryan L. Isacks

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Coupled Atmosphere-Ocean Processes and Primary Production in the Southern Oceans

Principal Investigator—**Mark Abbott**

Science Background

The Southern Ocean plays a critical role in the physical and biogeochemical dynamics of the ocean/atmosphere system through its role in carbon cycling and heat exchange with the atmosphere. The Antarctic Circumpolar Current, which links all of the major ocean basins, regulates the oceanic component of the southward poleward heat flux. Most ventilation of the deep ocean occurs in the Southern Ocean where density layers outcrop at the sea surface. Through cooling, mixing, and sea ice formation, new water masses are produced which sink into the ocean interior and replenish the deep and intermediate waters of the global ocean.

Carbon fluxes in the Southern Ocean are a significant component of the global carbon cycle. Since individual subsystems within the Southern Ocean can act as either sources or sinks of carbon dioxide, and our sampling is so poor, it is not known if the region as a whole is a source or sink for atmospheric carbon dioxide. Measurements of carbon dioxide in the atmosphere and in the upper ocean suggest that the Southern Ocean is one of the primary sinks for atmospheric carbon dioxide. Yet recent models suggest that the Southern Hemisphere has no net uptake of carbon dioxide by the ocean. One explanation for this discrepancy between field measurements and modeling is the sparse sampling in the Southern Ocean. As this region is noted for its intense spatial and temporal variability in nearly all processes, it is possible that either the field measurements are not sampling these processes adequately or that the models have not resolved them.

Of perhaps greater importance, processes in the Southern Ocean that regulate carbon fluxes are especially sensitive to the impacts of climate change. Numerical models suggest that subtle latitudinal shifts in the core of the westerly winds will greatly affect processes related to intermediate water formation and hence ocean circulation. Changes in water vapor transport can affect air/sea fluxes, thus impacting the rate of deep convection and deep water ventilation. Such changes in atmospheric forcing will have complex feedbacks with sea ice formation which, in turn, impact deep water formation and stratification.

Science Goal

Our focus is to develop coupled physical/biological models that can eventually be used in a predictive mode to understand the effects of changes in physical forcing of the ocean.

Current Activities

We are developing fully assimilating models of the coupled biological/physical processes regulating primary productivity in the Southern Ocean. These models will be used to understand the linkage between the intense variability observed on small scales and the larger-scale processes that occur on monthly and longer time scales. Our assumption is that neither models nor data alone can provide the necessary information on the appropriate time and space scales essential for understanding the role of the upper ocean in the Earth system. In essence, observations will always be undersampled, and models will always rely on some level of parameterization and simplification. The challenge is to build on the strengths of both and construct modeling and observing systems that can make forecasts with known error bounds.

Use of Satellite Data

Satellite data are used in several ways in this program. First, analysis of specific data sets through the use of long time series and ensembles of specific processes help guide model development. For example, if a particular relationship between phytoplankton biomass and wind stress curl is apparent, can the models reproduce this behavior? Second, data are used to validate model output and quantify model accuracy. In essence, data analysis will provide the control points with which to evaluate the progress of the model development activities. Third, data are assimilated into a variety of predictive models ranging from limited process models to comprehensive ocean/atmosphere models.

We rely on all of the ocean-related satellite sensors. TOPEX/Poseidon and the EOS radar altimeter will be used to study large-scale changes in ocean circulation. Coupling the EOS altimeter data sets with other altimeter data (such as Geosat Follow-On) will allow us to construct higher resolution circulation fields to study mesoscale processes. Infrared observations from MODIS and the NOAA infrared imagers will be used to study sea surface temperature for studies of air/sea fluxes. Coupled infrared/altimeter observations will be used to calculate high-resolution ocean circulation fields. Scatterometers (NSCAT, SeaWinds, and the ESA scatterometer series) will provide measurements of the basic wind-forcing fields. Higher level fields, such as wind stress curl, provide critical information for models of ocean circulation. Passive microwave radiometer (SSM/I and MIMR on EOS) measurements are to be used to calculate latent heat fluxes. These data will be combined with observations from CERES to improve estimates of boundary layer fluxes.

We will rely on MODIS and EOS Color (as well as other ocean color sensors such as SeaWiFS, OCTS, MERIS, and GLI) to provide basic information on ocean biological processes. These sensors will be used to estimate phytoplankton abundance as well as growth rates (based on models that incorporate biomass, fluorescence, and incoming solar radiation). Concentrations of dissolved organic matter (derived from MODIS) are an essential component of upper ocean carbon cycling. MODIS-derived estimates of water transparency will be combined with estimates of air/sea heat and momentum fluxes to calculate mixed layer depths.

These data sets, when combined with a suite of assimilation models, will allow us to investigate the effects of a changing environment on the structure and functioning of the upper ocean ecosystem. We expect that large-scale changes, such as decreasing stratospheric ozone (which will increase surface UV radiation) and changing patterns of wind forcing as a result of climate change, will greatly affect the patterns of upper ocean heat flux and carbon cycling. Our models will enable us to systematically examine the response of the upper ocean to these changes, and these predictions will be made with known error bounds.

Participation in Field Programs

In addition to modeling and satellite data analysis, we have begun a field component in our project. Some of our team members have extensive field experience in the Southern Ocean in both biological and physical measurements. We will deploy a bio-optical mooring in the Antarctic Circumpolar Current in late 1995 in conjunction with a U.S./Australia ocean circulation study. The mooring will first be tested at the Hawaii Joint Global Ocean Flux Study (JGOFS) Time Series station in early 1995. We have participated in a cruise in the Weddell Sea, using bio-optical drifters and photosynthesis measurements to improve our models for estimating primary productivity from fluorescence measurements made by MODIS. We expect to participate in the U.S. JGOFS program in the Southern Ocean which should begin during the next few years.

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Principal Investigator
Mark Abbott

Mark Abbott has been involved in the fields of oceanography and ecology for 12 years. He received his undergraduate degree in Conservation of Natural Resources from the University of California—Berkeley, and a Ph.D. in Ecology from the University of California—Davis. He has been affiliated with Oregon State University since 1988, currently as Professor in the College of Oceanic and Atmospheric Sciences. Dr. Abbott has served on numerous EOS-related committees, including the EOS Science Steering Committee and the Moderate-Resolution Imaging Spectroradiometer (MODIS) Panel. His research interests include studies of coupled biological/physical processes in the upper ocean and phytoplankton photosyntheses. He has been selected as a MODIS Team Member, and is a member of the International Geosphere-Biosphere Program (IGBP) Global Ocean Euphotic Zone Working Group.

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Global Water Cycle: Extension Across the Earth Sciences

Principal Investigator—**Eric J. Barron**

Science Background

This Interdisciplinary Science Investigation 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, regulates, and responds on both global and regional scales. The primary research strategy involves generating a hierarchy of simulation models—from general circulation models of the atmosphere, to mesoscale models, to basin-scale hydrologic models—and validating them against EOS and other global observational data. The coarse spatial resolution of current global climate models is frequently cited by the U.S. Global Change Research Program (USGCRP) as one of the major limitations in global change predictions.

The hierarchy of models, in conjunction with EOS observations, will make it possible to extend the predictive capability across a wide spectrum of spatial scales for different regions of the Earth's surface. The EOS observations will contribute to the development of an improved understanding of key processes, including cloud cover and radiative transfer characteristics, and energy and moisture fluxes at the interface of the atmosphere with the oceans, cryosphere, and land surface.

Science Goals

The objectives are to simulate future climate change on a global scale and, through coupling or "nesting" with higher spatial resolution models, to develop predictions of climate change on the scales appropriate to human activity. In linking climate and hydrologic forecast models, this investigation also strives to address a critical area of uncertainty—changes in the water balance associated with natural variability and climate change. The intent is to produce regional-scale predictions of changes in water balance and river flow as a function of climate change. Such predictions are characterized by many uncertainties and initially the investigation may only produce a better assessment of the areas of uncertainties in producing regional-scale predictions. However, this understanding will undoubtedly lead to a better capability to do high-resolution climate model predictions on a global scale.

Current Activities

The focus of this effort is currently on the Susquehanna River Basin of Pennsylvania, but the methodology is being developed for applications for any region of the globe. Near-term plans include the Ohio River Basin and the Tennessee River Basin. These efforts will allow us to contribute significantly to the GEWEX Continental International Project (GCIP) centered within the Mississippi Valley. Future research efforts will expand to additional regional foci, including oceanic and polar regions.

Participation in Field Programs

Participation in two field programs has added an important element to model development and validation. Participation in the CaPE Experiment (Convection and Precipitation/Electrification) focused on methods to diagnose large-scale land and atmosphere water budget components with the objective of applying these techniques over regional-scale areas in conjunction with GEWEX. MAC (Multi-sensor Airborne Campaign) Hydro '90 was conducted over the Mahantango watershed in

Pennsylvania, the central test area for this investigation. The objective of the campaign was to improve our ability to remotely determine the near-surface soil moisture.

The development and verification of the nested hierarchy of simulation models is strongly tied to field programs, such as MACHYDRO and CAPE.

Use of Satellite Data

EOS observations such as temperature, humidity, and precipitable water profiles from AIRS, AMSU, and MHS will be utilized in model development and later as part of a regional 4-dimensional assimilation and global analysis of multiphase water and temperature and diabatic heating. ASTER and MODIS surface radiance, reflectance, surface temperature, and vegetation measures will provide inputs for the SVATs (soil, vegetation, atmosphere models) to be used in the model predictions of energy and water fluxes. A major focus of the investigation will be improved cloud parameterizations in mesoscale and global atmospheric models, for which CERES and MISR measurements will be a key for both cloud properties and cloud radiative transfer. MIMR estimates of precipitation rates, atmospheric liquid and ice bulk microphysics, sea ice, cloud cover, ice, snow, and soil moisture will be critical for assessing both global and regional models and for development and evaluation of the SVAT models. Scatterometry from NSCAT and SeaWinds will aid substantially in the determination of air/sea energy and moisture fluxes and GLAS altimetry will be of considerable significance in assessing model predictions of ice sheet mass balance.

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Eric Barron received M.S. and Ph.D. degrees in Oceanography and Climatology from the University of Miami, and was a postdoctoral fellow at the National Center for Atmospheric Research (NCAR). Dr. Barron joined Pennsylvania State University as Director of the Earth System Science Center in 1986, and presently serves as a Professor of Geosciences as well. His research interests focus generally on global change and more specifically on numerical modeling of the climate system and the study of change throughout history. He is a member of numerous working groups related to these interests; in addition, he serves as Editor of *Global and Planetary Change.*

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Biogeochemical Fluxes at the Ocean / Atmosphere Interface

Principal Investigator—**Peter G. Brewer**

Science Background

This investigation focuses on 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.

There are three gases of intense interest due to their importance in the radiative forcing of the atmosphere and their likely role in global climate change. Carbon dioxide (CO_2) has long been recognized as an important climate change component. Dimethyl-sulfide (DMS) more recently has been connected with the albedo influence of clouds through its cloud condensation nuclei potential. Carbon monoxide (CO) is closely related to the oxidizing potential of the lower atmosphere through its rapid interaction with the hydroxyl radical, and the oceanic flux of CO is only now being constrained. In order to observe, from space, the global, time-evolving generation and destruction of these radiatively active gases at the ocean-atmosphere interface, a model (or series of models) must be in place to translate the variability of certain remotely sensed proxies into the temporal and spatial variability of oceanographic biogeochemical processes and their influence on these gases as they interact with the atmosphere.

Science Goals

In order to attain its specific goals, this IDS team is grouped into three interconnecting subgroups: optics, gases, and modeling/remote sensing.

The objective of the "optics" subgroup is to investigate some fundamental properties of major classes of marine phytoplankton and phytoplankton exudates (dissolved organic matter [DOM]) and to develop algorithms to correlate remotely sensed in-water optical properties with concentrations of phytoplankton, pigments, and dissolved organic matter.

The objective of the "gases" sub-group is to better quantify the fluxes of CO_2, CO, and DMS across the ocean-atmosphere interface. Our principal focus is on the quantification of the spatial and temporal variation of the concentration of these gases in the surface ocean and on the ocean-atmosphere exchange coefficient of each of these gases.

The objective of the "modeling and remote sensing" subgroup is to link the other two subgroups by developing coherent global upper ocean model(s) designed to use remotely sensed properties to quantify the spatial and temporal variability of the CO_2, CO, and DMS fluxes across the ocean-atmosphere interface.

Current Activities

In preparation for the launch of the EOS AM-1 platform, the team has been doing the necessary ground work to prepare for the remotely sensed data stream. Two major field programs (see below) are under way. A wealth of additional field and laboratory data is being analyzed to provide evidence to support or reject hypotheses regarding the processes that control the flux of radiatively active gases between the ocean and the atmosphere.

Tasks now underway, or recently completed, include:

a seasonal study of the optical, chemical, and photochemical properties of near-shore, shelf, slope, and oligotrophic sea waters; in-water measurements of photosynthetic pigments and phytoplankton biomass distributions to include photosynthetic accessory pigments in current ocean color algorithms and biomass in gas transfer models; completion of the second year of time-series measurements of DMS and its precursors, phytoplankton dimethylsulfoniopropionate (DMSP) and dissolved DMSP; work on a methodology for improving estimates of the global sea-to-air fluxes of DMS from ocean color measurements; development of a more-accurate gas transfer velocity parameterization based on wind speed, CZCS-derived organic matter estimates, and TOPEX/Poseidon-derived wave slope measurements; analysis of the spatial and temporal variation of partial pressure of CO_2 in the upper ocean to quantify the seasonal flux of CO_2 across the ocean atmosphere interface; development of the technology for *in situ* real-time sensing of the radiatively active gas, CO_2; expansion of the relationships between DOM distributions and various in-water optical properties and other measurements; and obtaining and reducing large data sets for analyzing CO cycling in oligotrophic and coastal ocean areas.

A modeling initiative in Monterey has begun, overlaying the oceanic CO_2 system on an eddy-resolving world ocean model. Other activities include: developing ecosystem models for inclusion in 3-D GCM's and integrating various models being spun-up at this time; developing a global primary production model and relationships in the airborne oceanographic lidar (AOL)/ship data collected in conjunction with coordinated field programs; and installation of a local low-cost HRPT station at the Monterey Bay Aquarium Research Institute (MBARI), using this to guide and interpret ocean observations.

Use of Satellite Data

Key to the investigation will be the assimilation of remotely sensed data that spans from the visible to the microwave portions of the electromagnetic spectrum. SeaWiFS, with its improved spectral capability relative to CZCS, will be used to identify pigments, and then the greater capability of MODIS will be applied to give estimates of phytoplankton functional groups through their pigment assemblage. Also, sea surface temperatures will be derived from SeaWiFS and MODIS. CERES will provide important radiation information about the shortwave heat flux to, and the longwave heat flux away from, the ocean surface. NSCAT and SeaWinds will provide ocean surface wind magnitudes, necessary for determining trace gas exchange, and also the vector information necessary for supplying momentum transfer to upper ocean mixing models. Radar ALT will be used to explore the relationship between mean-squared slope and normalized radar back scatter to reveal the presence of wave-dampening surfactants, which influence the rate of trace gas exchange with the atmosphere. MIMR data will be used for precipitation estimates, and AIRS/AMSU/MHS data will be used for atmospheric humidity measurements needed to make latent heat flux estimates over the ocean.

Participation in Field Programs

Team members have participated in several ocean-going research cruises. In September 1992 a significant field experiment was carried out in Monterey Bay on the R/V Point Lobos along with NASA P3 flyover support including lidar and associated instrumentation. A series of four-day cruises in August and November 1993 and in March and April 1994 were conducted on the R/V Cape Henlopen. There were also aircraft overflights of NASA's AOL in concert with these cruises. This seasonal study has allowed a more-complete optical characterization of the way in which organic matter interacts with impinging solar radiation. The AOL was employed to acquire active measurements of colored dissolved organic matter (CDOM) and chlorophyll fluorescence and passive measurements of reflectance. This work has already shown that the quantum yield of CDOM is close to constant over wide oceanic areas and, thus, fluorescence can be used to retrieve CDOM absorption coefficients.

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

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Northern Biosphere Observation and Modeling Experiment (NBIOME)

Principal Investigator—**Josef Cihlar**

Science Background

Numerous studies using General Circulation Models (GCM) have concluded that rapid climate change is likely to occur during the next century, principally as a result of the rising concentration of anthropogenic greenhouse gases. Air temperature is predicted to increase more at northern latitudes, and significant mid-continent drying has also been postulated. Such changes would strongly influence the functioning of northern terrestrial ecosystems as well as, over time, their structure and geographic distribution. They would in turn affect the climate because of the biosphere-climate feedbacks, at both mesoscale and GCM grid scales. The types and degree of likely ecosystem responses are not well understood but they will vary with the biome under consideration (forest, agroecosystems, wetlands, tundra) and the particular processes. In addition to climate change, natural ecosystems are increasingly affected by human activities. A critical issue in understanding the impact of climate change on ecosystems is the relationship between processes operating at various spatial scales, from leaves to landscapes. Satellite observations combined with flux data provide the key measurement techniques to allow bridging this range of scales for process studies and change monitoring.

Science Goal

The goal of the Northern Biosphere Observation and Modeling Experiment (NBIOME) is to improve the understanding of the relationship between the climate and the northern ecosystems, including their seasonal and interannual dynamics and their role in the global carbon cycle. The objectives of NBIOME are 1) to develop and validate methods for the extraction of biophysical parameters from optical and microwave satellite data for major Canadian biomes; 2) to develop methods for extending measurements or process understanding embedded in models across a range of spatial scales, from stand to landscape; and 3) to use the satellite-derived parameters with data from other sources as input to models for the assessment of ecosystem performance. These objectives will be achieved through a cooperative effort involving the Co-Investigators and their sponsoring agencies.

Regarding Objective 1, the parameters of interest are those which most closely characterize vegetation and its functioning: land cover type, land cover change, leaf area index, absorbed photosynthetically active radiation, and newly burned areas. Methods will be developed using present satellite data, especially AVHRR data over Canada as a precursor of EOS MODIS, and will include refinements of the processing techniques to compensate for subpixel clouds and bidirectional effects. This work will enable production of derived data sets for Canada during the pre-launch EOS period. Objective 2 addresses the problem of scaling for contagious processes, especially disturbance agents where temporal and spatial dynamics are intrinsically linked. Of special interest are disturbance processes at the mesoscale level. The principal ecosystem variable of interest in Objective 3 is the estimation of primary productivity. To be practical, productivity models should require a minimum of data that cannot be obtained from satellites or cannot be cost-effectively obtained over large areas. The focus of this study is on satellite data sources and techniques that may be used to apply findings from the study areas at the regional level.

Current Activities

NBIOME Co-Investigators are currently engaged in activities related to all three objectives above. Regarding Objective 1, research is underway to develop and validate algorithms for the extraction of leaf area index, absorbed photosynthetically active radiation, and land cover from satellite optical data. Research on the extraction of biophysical parameters from SAR data will be initiated in the near future. Objective 2 is approached through modeling fire spread as the most important contagious process in the boreal forest, and the testing of models describing the relationships between key ecosystem processes and their spatial and temporal scale domains. Two types of models are of interest in Objective 3: *production efficiency models* which require mostly satellite data and *ecological models* for which meteorological and other ancillary data sets must also be available. Investigations are underway using data from forest sites in Ontario and Quebec to test the two types of models. In central Canada, data from BOREAS will be used for the same purpose.

Use of Satellite Data

To date, the use of data from the NOAA Advanced Very High Resolution Radiometer (AVHRR) has been emphasized. A new system was built to produce full-resolution 10-day composites over Canada's landmass during the growing season, and methods were developed to reduce the noise resulting from the compositing process. Higher level products are being developed from the AVHRR data. The algorithms are being developed so that they can be readily transferred to EOS MODIS. Landsat data are the principal source of higher resolution data. ERS-1 and soon-to-be-launched Radarsat will be the primary source of SAR data.

Participation in Field Programs

NBIOME Co-Investigators have participated in field programs organized by the BIOME-TEL project (1992) and in BOREAS field campaigns (1993, 1994). The possibility of a field experiment in eastern Canada during the growing season of 1996 or 1997 is under consideration.

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NCAR Project to Interface Modeling on Global and Regional Scales With EOS Observations

Principal Investigator—**Robert E. Dickinson**

Science Background

The various activities in this investigation are all directed toward improving climate models and their predictions of global change. Because of the number and complexity of climate processes, these activities must be interdisciplinary in scope, bringing together the best possible surface and atmospheric data sources via the development of data systems and archives. The analysis and comparison of this data to model results improves the formulation of interactive processes in current climate models and gives a better understanding of the underlying physical processes.

Science Goals

The primary foci of this investigation are to: 1) develop and enhance methods to obtain and archive geophysical parameters from EOS sensors that will improve climate models; 2) develop and enhance methods for assimilating EOS data that are important to improving climate models; and 3) develop new methods for using EOS observations to assess and improve climate model treatments of surface-atmosphere interactions, the hydrological cycle, the global energy balance, cloud and aerosol radiative fields, and atmospheric chemical cycles.

Current Activities

The overall objectives of this investigation are manifested in a number of specific tasks in the following areas:

Surface Properties and Processes: Appropriate treatments of land-surface parameters and retrieval techniques are being developed, taking into account the high degree of sub-grid-scale variability and the need to distinguish between the wide variety of surface and vegetative properties. The surface models being treated include, especially, land surface models, such as the Biosphere-Atmosphere Transfer Scheme (BATS), but also sea-ice models.

Clouds and Planetary Energy Balance: Clouds have a significant impact on the planetary energy balance and are the most difficult atmospheric property to model. New, more detailed and interactive schemes for representing cloud physical and radiative properties are being developed as are improved means of validation. Global data sets and error statistics are also being developed for surface temperature, water vapor, and cloud fields (collaborating with and making use of the Pathfinder Program).

Data Assimilation: The data assimilation efforts are concerned with guiding the use and combination of data from the various sensors and *in situ* measurements into data sets. Research on this component includes efforts to: 1) evaluate the products of EOS data assimilation and their associated errors; 2) improve the development of the EOS data assimilation system by performing complementary studies of some of its important aspects; and 3) develop data analysis techniques to assimilate new types of data. Investigators have developed a 4D Variational Data Assimilation system using the adjoint method with full model physics that is especially designed to assimilate satellite-observed data.

Diagnostic Analyses: Detailed properties of climate models are being tested against global data obtained from various DAACs, the Goddard Data Assimilation Office (DAO), and archives being developed and maintained at NCAR for various data assimilation products. Methods are being developed that use observed variations in trace gases to test the transport in atmospheric models.

Use of Satellite Data

Data from EOS AM instruments, especially MODIS and MISR, will be used to retrieve the surface parameters needed for BATS to characterize the important sub-grid-scale variability, and annual and interannual variations. These parameters include surface albedos and various characterizations of vegetation cover for relating to model parameterizations of biophysical and biochemical properties. Within the constraints imposed by the data, modeled soil water and energy fluxes will be improved.

Significant advances are anticipated in the area of clouds and planetary energy balance with the availability of EOS data. Model representations of cloud fractional cover, cloud radiative properties and cloud ice/water amount will be enhanced with the improved retrievals available from MODIS, MISR, CERES, MIMR, and AIRS. The vertical partitioning of radiative energy available from CERES will be used to validate that simulated by the model.

A variety of EOS data will be addressed in the data assimilation studies. Of particular interest are the precipitation estimates, and temperature and relative humidity profiles obtained by the MIMR and AIRS/AMSU instruments as well as the cloud property retrievals from these instruments and MODIS, MISR, and CERES.

EOS data will be used to provide improved estimates of surface-atmosphere interactions and the hydrological cycle budget in order to validate and improve the hydrological processes in climate models.

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Principal Investigator
Robert Dickinson

Robert Dickinson has been contributing to the fields of climate modeling and global change research for over 25 years. He received his Ph.D. from the Massachusetts Institute of Technology in 1966 and shortly thereafter joined the staff of NCAR. In 1975, he became Head of the Climate Section and, in 1981, Deputy Director of the Climate and Global Dynamics Division. He is currently Regents Professor at the University of Arizona Department of Atmospheric Sciences. He has been active in many capacities as a member of the U.S. National Academy of Sciences, the American Geophysical Union, and the American Meteorological Society and through active participation in committees, panels, and working groups of the National Research Council, the International Geosphere Biosphere Programme, the World Climate Research Programme, and the Intergovernmental Panel on Climate Change. He is currently the editor of the *Journal of Climate*. Awards received by Dr. Dickinson include: the AMS Meisinger Award in 1973, the AMS Jule G. Charney Award in 1988, and the AMS Walter Orr Roberts Lecturer in Interdisciplinary Sciences in 1995.

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

Principal Investigator—**Jeff Dozier**

Background

Seasonally snow-covered areas of the Earth's mountain ranges are an important component of the Earth's hydrologic cycle, even though they cover only a small fraction of the Earth's surface. These alpine regions are a major source of water for runoff, ground water recharge, and agriculture. Moreover, these regions are sensitive to changes in climate and to the amount and chemistry of snowfall, because of their small groundwater reservoirs, the predominance of intrusive igneous rocks that weather slowly, thin acidic soils, the large amount of precipitation, and typical basin low buffering ability. Because of this sensitivity, changes in precipitation chemistry translate into changes in stream chemistry more rapidly than in basins with deeper soils.

Knowledge of the hydrologic cycle in these areas is limited by poor understanding of the processes that determine the cycle. Specifically, we have imprecise knowledge about the spatial and temporal distribution of the rate of snow melt, the chemistry of the snow, water flow in the snow and its chemical concentrations, and the routing of water from the snow pack through the drainage basin. Because of the rugged terrain in alpine basins, it is difficult to collect sufficient data to characterize and model these processes.

Science Goals

In an attempt to gain better understanding of Alpine Basin Hydrology, this investigation will use remotely-sensed data from several EOS-era instruments in conjunction with field data to monitor hydrologic conditions in watersheds and to drive hydrologic models. It seeks a fundamental understanding of the cycling of water, chemical species, and nutrients in alpine basins, and thus an ability to identify changes caused by changing climate or changing precipitation chemistry.

Current Activities

Snow mapping at subpixel resolution with Landsat data: Spectral mixing analysis enables estimation of the fraction of snow, rock or soil, and vegetation in each 30 m pixel. The technique was verified with high-resolution (< 1 m) aerial photos. It is as accurate as the air photos, but can be used over much larger areas at much lower cost.

Snow mapping, estimation of grain size, and estimation of surface liquid water with AVIRIS (Airborne Visible and Infrared Imaging Spectrometer): Examination of spectral absorption features enables estimate of the surface grain size, and recent modeling results show that we can derive liquid water content of a thin surface layer. The grain size estimates were verified with field data, and they are independent of illumination angle. Knowledge of the grain size allows calculation of the spectral albedo.

Synthetic aperture radar (SAR) investigations with data from AIRSAR and SIR-C/X-SAR: With an airborne or spaceborne SAR, snow can be mapped in any weather condition with an accuracy of about 85%. Although instruments in the optical wavelengths, e.g., Landsat, provide more accurate snow maps, they are restricted to clear weather. The SAR data can also estimate the liquid water content in the top layer of the snow pack. Combining this information into a distributed snow-melt model that predicts the timing and magnitude of snow-melt runoff from energy balance parameters is one of our future challenges. Such a model could be a powerful management tool for forecasting runoff, and, hence, maximizing water yield and minimizing the impacts of floods.

Developing data-centric information management systems: Our studies of global hydrology and management systems hydro-chemistry result in an accumulation of massive amounts of scientific data. We are addressing the need to manage these large, complex data sets, so that the data are effectively and efficiently ingested, stored, maintained, retrieved, and analyzed. Prototype systems are in development for handling imagery, managing field data, and creating scientific products. Some capabilities of the systems include the ability to store and retrieve data from disparate computing environments in a "seamless" fashion; generate scientific products; access a variety of analysis tools; track processes applied to data; view imagery, field notes, and maps; browse and select data of interest; and provide an intuitive user interface.

Use of Satellite Data

In the EOS era, techniques initially carried out with Landsat data will be extended to subpixel snow mapping from MODIS and ASTER. With such analyses, MODIS will be useful in alpine regions. Also, data from HSI (Hyperspectral Imager) on "Lewis," part of the Small-Spacecraft Technology Initiative (SSTI), will provide images of high spectral resolution comparable to AVIRIS. SAR investigations that are now being pursued with advanced aircraft-mounted systems may be continued using simplified techniques with single-frequency, single-polarization SAR instruments such as ERS-1, JERS-1, and Radarsat to provide useful snow-mapping data.

Participation in Field Programs

Examination of the biogeochemistry of mixed-conifer catchments in the Sierra Nevada using 10 years of data on precipitation inputs, stream discharge, and stream chemistry has shown that precipitation over the period varied widely, but that precipitation chemistry was nevertheless similar. Solute concentrations were higher in rain than in snow, and dry deposition constituted a major portion of the nitrogen and sulfur inputs. Although strong soil alkalinity buffered acidic inputs from wet deposition, brief decreases in stream pH occurred during larger storms. These data show that the close relationship between precipitation chemistry and stream chemistry occurs in the subalpine forested zone, as well as in the high alpine zone with only sparse trees and thin soils.

Field measurements in the Rocky Mountains have investigated nitrogen-cycling processes under the snow pack. The data show a trend in the last decade toward nitrogen saturation in the high-elevation catchments. Normally these basins do not export nitrogen; the biota consume all the nitrogen before it leaves the basin. However, deposition of extra nitrogen in the precipitation has apparently caused these basins to become nitrogen saturated.

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Principal Investigator
Jeff Dozier

Jeff Dozier, Dean of the School of Environmental Science and Management at the University of California, Santa Barbara, received his B.A. from California State University, Hayward in 1968 and his Ph.D. from the University of Michigan in 1973. He has taught at UC Santa Barbara since 1974. From 1990 to 1992 he served as the EOS Senior Project Scientist. He has published extensively in diverse fields of research including snow hydrology, Earth system science, radiative transfer in snow, remote sensing and data systems, image processing, and terrain analysis. With Dr. Ghassem Asrar, he is the co-author of *EOS: Science Strategy for the Earth Observing System*. He is co-principal investigator on the University of California's Redwood project, that seeks to develop a next-generation distributed information system and computing enterprise. Dr. Dozier is a Fellow of the American Geophysical Union and a Distinguished Visiting Scientist at the Jet Propulsion Laboratory. From 1990 to 1993 he was Editor of *Geophysical Research Letters*. He is a member of the Computer Science and Telecommunications Board of the National Academy of Sciences. In 1993 he received the NASA Public Service Medal.

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International Co-Sponsor—**Brazil**

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

Principal Investigator—**Joao V. Soares**
Lead U.S. Investigator—**Thomas Dunne**

Science Background

Amazonia is unique among terrestrial ecosystems because of its extent, the intimate interaction with the largest river on the planet, and the rate of change caused by human activity. Environmental conditions in the Basin range from high mountains to equatorial lowlands, and are subject to natural and anthropogenic changes. Both natural and anthropogenic changes in the Amazon are expected to disrupt regional vegetation distributions, alter the physical and chemical characteristics of the continental-scale river system, and modify regional hydroclimatology with significant potential to influence global climate patterns. Understanding process dynamics of the Amazon Basin under natural and disturbed conditions is of high scientific priority and is an essential prerequisite for modeling global change and for understanding the resulting public policy issues.

Science Goal

The goal of this investigation is to understand the routing of the mobile terrestrial materials (water, sediment, and nutrients) from precipitation, through the landscape and drainage system, to the atmosphere and ocean under conditions of changing climate and land use.

Current Activities

The EOS Amazon group uses field sampling, hydrometric databases, computer models, and remote sensing to study the sources, transport, and processing of water, sediment, and solutes within the Basin as they are governed by the large-scale features of the terrain, atmospheric processes, and vegetation characteristics.

Use of Satellite Data

In addition to using currently available data, the group is preparing, through development of remote sensing tools, computer models, and data management systems, to maximize the utility of data from EOS sensors. They are exploring the usefulness of MODIS-type sensors for monitoring the status of forest canopies and using the information in their computations of hydrologic response, primary production, and nutrient cycling. The group has made comparisons of AVHRR records and TM images of the forested parts of the Basin in order to learn what aspects of the land cover can be reliably measured from coarse-resolution images. They have been developing algorithms, for application to new imaging systems, which take into account the full range of background variation in spectral variability due to atmosphere, instrument, and other non-vegetative scene components as opposed to optimizations based solely on the spectral contrast of the target material. MODIS has the capability to provide variable resolution band passes. The Amazon group's focus is to optimize these band passes, based on the contrast between foreground and background, given the natural variability that exists within these defined groups.

The fore-and-aft viewing of ASTER allows separation of many atmospheric influences from that of the surface in addition to the goal of making stereo pairs. The inclusion of the thermal channels in ASTER also allows for better detection of even simple scene components such as vegetation.

The group has also been incorporating satellite measurements of solar radiation fluxes and the results of numerical weather simulations into their hydrologic models and comparing the data with sparse ground-level measurements in order to learn about the accuracy and utility of future large sets of environmental data for monitoring and interpreting the condition of the Basin surface.

Participation in Field Programs

Field studies by the group concern rivers and flood plains at all scales throughout the Basin, as well as well-drained forested parts of the landscape. Measurements of vegetation characteristics in forested, cleared, and re-growth areas allow the interpretation of sequential Landsat TM, SAR, and AVHRR images of land cover. An important emphasis is the characterization of the vegetation and geomorphic characteristics of vast wetlands and mapping of the timing and extent of their inundation, using passive microwave data from SMMR and SSM/I, and from MIMR. This information is interpreted and linked to basin hydrology through analysis of empirical hydrologic data and mathematical modeling. The hydrology of these wetlands, which cover more than 20 percent of the Basin, is crucial to understanding the biogeochemistry of the river as well as the exchange of methane with the atmosphere.

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Principal Investigator
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Thomas Dunne

With a Ph.D. in Physics of Remote Sensing conferred by the University of Paris in 1986, Joao Soares has focused his research in the areas of modeling the biosphere/atmosphere interactions for water/carbon/energy fluxes and on remote sensing. He has worked on the problem of extracting soil moisture and vegetation structure from radar data in the context of the Space Radar Laboratory (SIR-C/X-SAR) experiment. He has been affiliated with the Instituto Nacional de Pesquisas Espaciais since 1987.

Thomas Dunne is Professor of Geological Sciences at the University of Washington. He holds B.A. and Ph.D. degrees in Geography from the University of Cambridge and The Johns Hopkins University, respectively, and is a Member of the National Academy of Sciences and the American Academy of Arts and Sciences. His research concerns field and theoretical studies of drainage basin and hill slope evolution, incorporating the relations among climate, vegetation, hydrology, sediment transport, and soil properties. In addition to work in several mountain and subarctic environments of North America, he has experience measuring hydrologic and sedimentation processes in tropical environments in Africa and Brazil, which he uses as the basis for computer modeling studies to generalize his findings.

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

Principal Investigator— **John S. Godfrey**

Science Background

The CSIRO Marine Laboratories employs physical and chemical oceanographers in its Division of Oceanography, and biological oceanographers and fisheries scientists in its Division of Fisheries. The CSIRO EOS Interdisciplinary Study aims to integrate existing Marine Labs research projects of relevance to EOS, using the Laboratories' substantial capability in satellite data acquisition and processing. In its initial phases, the Study was largely observationally based. These activities are now being complemented by the use of numerical models that assimilate EOS remotely sensed and other data.

First, an eddy-resolving model that assimilates altimetric and other data will cover the Australian Exclusive Economic Zone. This is intended for use by resource managers in studies of a wide variety of problems, including pollution, dispersion of fish and pest larvae, and search and rescue. It will be used for our Goals 2 and 3. A second model covers the Indian Ocean, and is intended to become part of a global coupled model (in collaboration with other Australian institutions) for studying climate change and variability, with particular emphasis on the Australian region. It will be used to further our work on Goal 1.

Science Goals

We have three goals: 1) to improve the quantification of air-sea interaction and oceanic heat storage, for the purpose of determining the ocean's role in climate variability and change; 2) to examine the carbon cycle in the waters surrounding Australia, and its influence on the global carbon cycle; and 3) to address the implications of interannual variability and long-term change in the regional oceanography for marine ecosystems, and commercial fisheries in particular.

Current Activities

Recent activities have included: Verification of TOPEX-Poseidon sea levels, against a tide gauge in northern Tasmania, to an rms accuracy of 4 cm; development of altimeter processing procedures for estimating surface eddy variability and Reynolds stresses; validation of net heat flux measurements during TOGA-COARE by explicit ocean heat budget closure, to an accuracy of better than 10 W/m^2 over a few days; completion of several deep hydrographic sections for the World Ocean Circulation Experiment (WOCE), including four from Tasmania to Antarctica. These cruises included biological measurements that will assist in assimilation of MODIS ocean color data into carbon cycle models.

Other activities included completion of three JGOFS cruises to the western equatorial Pacific. Productivity studies revealed a deep chlorophyll maximum along 155^o E, which shallowed in the 1992 ENSO event. The existence of this dominant subsurface maximum implies that care must be taken in remote sensing of biomass and production in this region.

A new research program has been developed on the impacts of climate variability in marine ecosystems and fisheries, making use of ongoing field research in S.E. Australia and northern Australia. There is also ongoing work on a model of the Indian Ocean that emphasizes near-surface thermodynamics. The completed Indian Ocean model will be a component of a global coupled model for simulating climate variability.

An eddy-resolving model of Australia's Exclusive Economic Zone (EEZ), that assimilates altimeter data has been developed. So far only the Tasman and Coral Seas have been modeled. Preliminary results indicate that TOPEX-Poseidon altimetry should revolutionize our ability to keep track of the copious eddies found around Australia. We anticipate that this model will be a major integrating tool for the work of the Marine Laboratories.

Use of Satellite Data

The development of the new models greatly increases our use of satellite data, particularly from AVHRR and from the TOPEX-Poseidon and ERS-1 altimeters. We work on a range of projects using remotely-sensed data:

- Development of "synthetic expendable bathythermographs (XBTs)," in which we use XBT data along existing lines in the Indian Ocean to estimate temperature anomaly profiles from surface steric height and SST alone. It is proposed to use these to complement the (very sparse) XBT data set throughout the Indian Ocean, using altimeter and AVHRR data.

- Development of sea level maps (and associated synthetic XBTs) in the eddy-rich Tasman and Coral Sea region, for use in initializing the EEZ model in this region. These uses will later be extended to cover the entire Australian EEZ.

- Use of CSIRO-generated AVHRR maps in studies of interannual variability of current systems around Australia.

- Analysis of seasonal and interannual variation in the historical CZCS pigment data for the Australian region. Plans have been made to receive and process SeaWiFS ocean color data.

- Data from geostationary and polar-orbiting satellites have been used to map solar radiation in Australian ocean regions.

- Southern Ocean Assimilation modeling, aimed at assimilating the time-varying T-P altimeter data into a prognostic primitive equation model, and diagnosing the role of eddies on the transport of momentum, heat, and freshwater.

Participation in Field Programs

Since 1990, CSIRO Marine Labs scientists have led 9 voyages of R/V "Franklin" and R/V "Aurora Australis" as part of WOCE in the period 1990-1995; 3 voyages of R/V "Franklin" in support of JGOFS; 4 voyages of R/V "Franklin" in support of TOGA-COARE; and 5 voyages of F/V "Southern Surveyor," in support of JGOFS.

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Principal Investigator
J. Stuart Godfrey

Stuart Godfrey graduated with a B.Sc. (Hons) from the University of Tasmania in 1961, and obtained his Ph.D. in high energy physics from Yale University in 1967. After a year's postdoctoral work at Harvard University, he joined CSIRO's Division of Fisheries and Oceanography in 1969. After a period of working with numerical models of the East Australian Current and the tropical Pacific (including the first study of the role of Kelvin and Rossby waves in ENSO-like disturbances), he turned to analytical and observational work. This has included studies of the strength of the Indonesian Throughflow and its effects on global climate, and accurate validation of net surface heat flux measurements by explicit heat budget closure in the ocean mixed layer. Recently he has been collaborating with others on combining altimeter and AVHRR data to obtain small-scale estimates of eddy activity in the Tasman and Coral Seas.

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

Principal Investigator—**Barry E. Goodison**

Science Background

The cryosphere is an important component of the global climate system involving complex feedback mechanisms of differing magnitude and sign. At the global scale, there is a large body of evidence documenting an inverse relationship between the amount of snow and ice on the Earth's surface and global mean temperature. There are, however, important regional exceptions to this generalization, and greater understanding of cryospheric processes and their spatial and temporal variability is required to reduce the uncertainties in modeling the global climate system. Improved understanding of cryospheric variability is particularly relevant in Canada where a wide range of economic activities are sensitive to variations in cryospheric elements.

Science Goals

The basic scientific goals of CRYSYS are to: 1) develop capabilities for monitoring and understanding variations in cryospheric variables across a range of scales; 2) to develop and validate local, regional, and global models of climate/cryospheric processes and dynamics to improve understanding of the role of the cryosphere in the climate system; and 3) to assemble, maintain, and analyze key historical, operational, and research cryospheric data sets to support climate monitoring and model development.

Current Activities

The broad goals of CRYSYS are being addressed through five scientific themes corresponding to the main elements of the cryosphere in Canada: glaciers and ice caps, sea ice, lake ice, snow, and permafrost. There is a CRYSYS data management activity to address data issues. Brief overviews of the activities of the scientific themes follow. The theme leader is identified for each component.

Glaciers and ice caps (M. Brugman): This component focuses on the development of new techniques for monitoring glaciers and ice caps with remotely sensed data and includes continuing enhancement and access to conventional glacier information in the Canadian Glacier Inventory.

Sea ice (E. LeDrew): CRYSYS sea-ice research focuses on field investigations for development and validation of microwave algorithms for first-year and multi-year sea ice and modeling of interannual variability and sea ice-climate feedback processes.

Lake ice (A. Walker): Lake-ice studies focus on the use of microwave satellite data to extract geophysical information related to lake-ice processes and the identification of freeze-up/break-up events for climate variability and change analysis.

Snow (A. Walker): Main thrusts in CRYSYS snow-related research are: 1) the development and validation of microwave algorithms for snow cover properties (extent, water equivalent, wet/dry state) in varying landscapes, and the synergism between active and passive microwave data for snow studies; and 2) reconstruction of historical snow cover from conventional and remotely sensed data to document and better understand long-term variability in snow cover.

Permafrost (C. Duguay): The permafrost research component addresses two issues of direct relevance to global climate change research in northern Canada:

1) the development of techniques for mapping the spatial distribution of permafrost using remotely-sensed and ancillary data; and 2) the development of algorithms for detecting changes in active-layer depth and terrain features characteristic of degrading permafrost such as ground-ice slumps and thaw lakes.

Use of Satellite Data

CRYSYS requires the effective combination of data from many conventional or ground data sets, from airborne campaigns, and from remotely sensed information from EOS and non-EOS platforms. Current passive microwave data from SSM/I on the DMSP platforms are the basis for the development of snow, lake-ice, and sea-ice algorithms for MIMR and future SSM/I sensors. SAR from ERS-1 and 2 and Radarsat are critical for snow, sea-ice, permafrost, and glacier investigations. AVHRR is the current sensor for large-area studies before MODIS becomes available in the EOS era. GLAS and ASTER will support targeted glacier and ice cap investigations. CRYSYS team members interact directly with the NSIDC and ASF DAAC facilities and Canadian agencies in most of their studies.

Examples of the use of current satellite data for CRYSYS research include: acquisition of DMSP SSM/I data in near real-time for the development of algorithms to derive snow-water equivalent, extent, and snowpack state for different landscape regions of Canada; SSM/I 85 GHz brightness temperature data for large lakes in northern Canada to discriminate between ice cover and open water, for monitoring freeze-up/break-up patterns for the entire lake; application of SAR data for improving glacier runoff modeling; and the practical application of SAR interferometry for topographic measurements on glaciers. The potential of multi-band SAR data (JPL AIRSAR) is currently being evaluated for mapping permafrost features, and ERS-1 SAR data is being evaluated for its ability to map permafrost features.

Participation in Field Programs

All CRYSYS components involve extensive field investigations for algorithm development and validation. Detailed measurements of geophysical properties of first-year and multi-year ice at the SIMMS field site near Resolute, North West Territories (NWT) have been conducted for five years. Extensive airborne and ground networks have been established over the Canadian prairies and the boreal forest area of central Canada for repeated ground measurement and gamma ray and passive microwave surveys for the snow algorithm research.

Two permafrost study sites have been established at Mayo, Yukon Territory (YT), and at Fosheim Peninsula, NWT, and intensive field campaigns have been mounted in the Mayo area over the past two summers to map surface cover and permafrost-related terrain features. Glacier and ice cap mass-balance measurements are continuing to be made at long-term monitoring sites in western Canada and the Canadian Arctic.

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Principal Investigator
Barry Goodison

Barry Goodison received his Ph.D. from the University of Toronto and has over 25 years of research experience in hydrometeorology, remote sensing of the cryosphere, precipitation measurement, and climate/cryosphere studies as a scientist with the Atmospheric Environment Service, Environment Canada. He has led several national and international field studies on components of the cryosphere, especially snowfall and snow cover. He recently led the World Meteorological Organization Intercomparison on the Measurement of Solid Precipitation, and was an investigator and organizer of the Boreal Ecosystem Atmosphere Study (BOREAS). He has served on, or chaired, many scientific committees and working groups, including several for NASA.

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

Principal Investigator—**William Grose**

Science Background

The EOS Program is structured to address the extent, causes, and effects of global climate change. An important element of the global change problem focuses on understanding the transport, chemical transformations, and the source/sink distributions of radiatively important gases, e. g. , CO_2, H_2O, O_3, and CFCs, in the Earth's atmosphere. Issues of global warming, ozone depletion, and the coupling of atmospheric chemistry and climate depend critically upon that understanding.

Science Goal

Dr. Grose and his team of co-investigators will examine the fundamental radiative, chemical, and dynamical processes that determine the circulation, the thermal structure, and the distribution of constituents in the Earth's atmosphere. This investigation will consist of a coordinated, broad-based program of model simulation studies and observational analysis focused on the troposphere and stratosphere. The modeling and data analysis studies will serve a dual purpose: 1) increase understanding of fundamental processes and their respective interactions; and 2) aid in the development of a predictive capability for global change studies. An overall emphasis of this investigation will be to contribute to providing a sound scientific basis for environmental policy decisions.

Current Activities

Observational studies and complementary model simulation studies are being conducted as part of this investigation using a hierarchy of models that incorporate radiative, chemical, and dynamical processes in varying degrees of complexity appropriate to the particular problem being addressed. These modeling studies can be used for understanding processes, testing hypotheses, and assessing the response of the atmosphere to global change influences. At present, both two- and three-dimensional chemistry/transport models are being conducted concurrently with the ongoing observational studies. In addition, an air parcel trajectory model including chemistry is being used in conjunction with meteorological data.

Currently, Dr. Grose, several of his LaRC co-investigators, and Dr. O'Neill (University of Reading) are also investigators for the Upper Atmosphere Research Satellite (UARS) program and have participated in both data validation activities and in science studies of stratospheric chemistry and dynamics using the UARS data sets. The most recent science studies have included: a comprehensive analysis of the 1991/1992 winter stratospheric circulation; an investigation of mixing processes in the polar night jetstream; analysis of dehydration associated with the springtime Antarctic vortex; studies of lower stratospheric transport using model simulations and tracer correlations from satellite and aircraft data; and chemistry and transport simulations with a 3-D model and comparisons with UARS data sets.

Drs. Solomon (NOAA Aeronomy Laboratory) and Garcia (National Center for Atmospheric Research) have developed an innovative 2-D chemistry/transport model incorporating a formulation for wave transport. The model is much less computationally intensive than comparable 3-D models and can be used as a precursor to a 3-D model study. It has been used to simulate distributions of constituents throughout the middle atmosphere, to calculate the global warming potential of various constituents, and to study the possible role of iodine compounds in the depletion of ozone.

Dr. Salby (University of Colorado) has concentrated on observational studies of tropical convection and equatorial wave dynamics. He will be evaluating the existing convection parameterization in the LaRC model and implementing improved techniques for use in the model. He has also demonstrated techniques for improved information retrieval using independent asynoptic data sets from multiple satellite platforms. In addition to ongoing science studies, considerable effort has been devoted to improving the LaRC 3-D model. The model (extending from the surface to the lower mesosphere) was originally developed to study middle atmosphere chemistry and dynamics. The model has been recently modified by incorporating a comprehensive tropospheric physics formulation. These modifications are consistent with recently expanded science goals related to tropospheric science issues. Concurrently, Dr. Olson has been developing the necessary revisions appropriate for tropospheric chemistry studies. This tropospheric chemistry formulation is being developed and implemented in both the LaRC and NOAA GFDL 3-dimensional models. The LaRc model has also been modified to produce a version in which radiative, chemical, and dynamical processes are mutually interactive. Preliminary simulations have been conducted with this version, and initial evaluations show good agreement with observations.

Use of Satellite Data

This investigation involves observational analysis and diagnostic interpretation of meteorological and constituent data from EOS instruments, in conjunction with other satellite, balloon, ground-based, and aircraft data. Chemical constituent data from MOPITT and TES, along with temperature and water vapor data from AIRS will be the primary EOS data which will contribute to our tropospheric science studies. Stratospheric science studies will rely upon chemical constituent data (and in some cases temperature) from MLS, HIRDLS, and SAGE III and temperature data from AIRS and AMSU. Wind and temperature data from assimilation models will also be utilized in the studies. The primary source of data prior to launch of the EOS platforms will be the data from the suite of instruments on UARS. Balloon and aircraft data will also be used in the science studies to help bridge the transition between the stratosphere and troposphere.

Participation in Field Programs

Drs. Grose and Pierce are Principal Investigators for the Airborne Southern Hemisphere Ozone Experiment (ASHOE), and are currently conducting studies of transport, mixing, and chemistry in the lower stratosphere using ER-2 aircraft data in conjunction with the UARS data. An air parcel trajectory model, including chemistry, is being used in conjunction with the ER-2 aircraft data to conduct science studies.

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Principal Investigator
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William Grose received an M.S. in Physics from the College of William and Mary and a Ph.D. in Aerospace Engineering from Virginia Polytechnic Institute and State University. He is a Senior Research Scientist and Assistant Head of the Theoretical Studies Branch, Atmospheric Sciences Division, at the Langley Research Center, where he initiated and guided the development of three-dimensional models for studying atmospheric dynamics and trace constituent chemistry and transport. His principal research interests are in the areas of atmospheric dynamics and trace constituent transport and chemistry. In addition to his role as Principal Investigator for this Interdisciplinary Investigation, he is a Principal Investigator and member of the Science Team for both the UARS and ASHOE programs. He also manages an element of the NASA Atmospheric Effects of Aviation Project. Dr. Grose has been a Visiting Scientist with the United Kingdom Universities' Atmospheric Modeling Group at the University of Reading and with the Hooke Institute at the University of Oxford. He was recipient of the NASA Medal for Exceptional Scientific Achievement in 1986.

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

Principal Investigator—**James E. Hansen**

Science Background

Global climate change has attained paramount interest in Earth sciences because of its potential to affect human activities and the environment. A crucial science issue is to understand the possible anthropogenic role in observed climate change. Mankind's alteration of the carbon cycle, through burning of fossil fuels and deforestation, is expected to significantly alter the planet's temperature and thermal energy cycle, and perhaps the most important impact of this will be on water distribution and the hydrologic cycle. Measurable changes in the carbon, energy and water cycles are occurring on a year- to-year basis. Analysis of these changes and their relationships has great potential to improve predictability of future climate change.

Science Goals

The ultimate objective of our study of the combined carbon, energy, and water cycles concerns global climate change, specifically an understanding of current and recent interannual climate variability and trends, as well as an ability to reliably predict the future climatic impact of anthropogenic activities. Achievement of the climate research goals is dependent upon appropriate global observations of climate forcings, feedbacks, and diagnostics, and thus our role in EOS and the overall NASA Mission to Planet Earth is to help define needed observations and to use these observations in our research as they become available during the EOS flight era.

Current Activities

Our present focus is on analysis of the change of the global energy, water and carbon cycles during the period after the 1991 eruption of the Mount Pinatubo volcano. The stratospheric aerosols produced by this volcano altered the thermal energy balance by an amount comparable in magnitude to the perturbation that will be caused by doubling of atmospheric carbon dioxide. Pinatubo thus provides an excellent opportunity to test our understanding of the sensitivity of these global cycles to a global, albeit short-term, forcing. Observational evidence exists for changes of global and continental temperatures, in atmospheric carbon dioxide and methane abundances, and patterns of precipitation. We are involved in both development of data sets to document these changes and modeling studies to interpret the changes.

Use of Satellite Data

Understanding of climate change can be achieved only if the major global climate forcings and radiative feedbacks are monitored with adequate precision, which accounts for special dependence of our studies on data from several EOS instruments. ACRIM and SOLSTICE will provide data essential to determination of the role of solar variability in global climate change. SAGE III will provide data on climate forcings due to changes of stratospheric aerosols, water vapor, and ozone. EOSP will measure tropospheric aerosols, the most uncertain of all anthropogenic climate forcings.

Measurements of long-term changes of cloud properties induced by aerosols and other anthropogenic effects represent a great challenge because of the needed precision and diurnal sampling. Mission to Planet Earth is expected to provide the possibility for these measurements through small Earth Probe satellites.

The most fundamental diagnostics for our climate analyses are precise changes of temperature in the atmosphere, on the surface, and in the ocean, along with the planetary radiation balance. Thus we rely on AMSU and MHS data from operational satellites and EOS, as well as radiosonde and meteorological station measurements. Ocean temperatures are provided by ships and buoys; acoustic tomography may provide information on future trends of internal ocean temperatures over large regions. CERES on EOS provides monitoring of the planetary radiation balance, and, in combination with MODIS and other EOS instruments, will allow comprehensive analyses of cloud processes.

Participation in Field Programs

The greatest uncertainty in global climate forcings is the poor knowledge of changes in anthropogenic aerosols in the troposphere. Because of the great difficulty in measuring aerosol properties with sufficient accuracy from space, we have helped organize a proposed international network of sun photometers, with the principal objective being measurement of aerosol changes. This proposed effort would involve students centrally in the data collection and analysis, thus contributing to science education as well as environmental studies.

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Principal Investigator
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James Hansen heads the Goddard Institute for Space Studies (GISS). A student of Astronomy and Physics (Ph.D. from the University of Iowa, 1967), he has focused his research primarily on radiative transfer in planetary atmospheres and related interpretation of remote soundings, development of simplified climate models and three-dimensional global models, and the study of climate mechanisms. In addition to his research and administrative duties at GISS, he serves as Adjunct Professor at Columbia University.

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Climate Processes Over the Oceans

Principal Investigator—**Dennis L. Hartmann**

Science Background

The surface climate of Earth is strongly influenced by the amount and distribution of water vapor, liquid water, and ice suspended in the atmosphere. The response of water vapor and clouds to a climate change is the single most important feedback process determining the magnitude of the climate change expected from forcings such as increasing carbon dioxide in the atmosphere. The processes that control water in the atmosphere are very complex and extend across a wide range of spatial scales from the few-centimeter scale of turbulence in the boundary layer to the tens of thousands of kilometers that characterize the scale of global atmospheric circulation systems. Seven-tenths of the surface of Earth is covered with ocean, so that the humidity and cloud structure of the global atmosphere are largely determined by processes occurring in oceanic areas. The climate over land areas is in substantial measure determined by processes that occur over the oceans.

Science Goals

The overall goal of this investigation is to achieve improved modeling of the atmosphere and its interactions with the ocean through use of new data from satellites as well as through use of existing data. The intent is to address the roles of circulation, clouds, radiation, water vapor, and precipitation in climate change, and the role of ocean-atmosphere interactions in the energy and water cycles. This investigation is contributing to a comprehensive understanding of climate and its natural variability, and thereby to reduced uncertainty in predictions of future climate changes.

Current Activities

Available satellite observations, *in situ* data, and global assimilated data sets, and a variety of models are being used to construct an integrated view of atmospheric climate over the oceans and to improve under-standing and modeling of climate feedback processes. The physical processes considered involve boundary layer dynamics and resulting fluxes, cloud-scale and mesoscale dynamics, cloud physics, and global-scale circulations. Interactions among clouds, water vapor, and radiation fluxes, and among various scales of motion from small scale to planetary scale are incorporated. Important phenomena being studied are described below:

Boundary layer fluxes of heat, momentum, and moisture: The vertical exchanges of heat, moisture, and energy across the planetary boundary layer are critical to both the oceanic state and the atmospheric state. These fluxes are being studied with observations and models.

Low-level clouds: Low clouds over the ocean are extremely important for the energy balance of Earth because their albedos are much higher than that of clear sky over ocean, and they have only a small effect on escaping longwave radiation. Albedos of low-level clouds may be sensitive to sulfur aerosols produced by humans. Long-term trends in low clouds and their relation to SST and other variables are being derived from long records of surface observations.

Tropical convective clouds: Deep convective clouds in the tropics are the primary mechanism whereby solar heating of the ocean is moved upward into the free troposphere where it can be transported poleward and eventually emitted to space. The spatial organization and temporal development of convective systems and their relation to large-scale conditions are being studied with data from geosynchronous satellites and global meteorological analyses. Water vapor data from TOVS and GOES are being used to study the effect of deep convection and associated large-scale circulations on the moisture budget of the upper troposphere of the tropics.

Mid-latitude synoptic systems: These systems produce most of the precipitation in midlatitudes, and the clouds associated with them comprise a rich mixture of convective, layered, and stratiform cloud structures, which have important effects on the energy and water balances in midlatitudes. Synoptic storms in midlatitudes are responsible for extreme modifications of the planetary boundary layer and intense interactions with the ocean, which are being studied with scatterometer data.

Use of Satellite Data

Models of the boundary layer are being combined with information from satellites such as ERS-1&2, SSM/I microwave measurements, global weather analyses, and *in situ* measurements to estimate surface fluxes and to understand their relationship to atmospheric and oceanic phenomena. Information about surface wind speed from SeaWinds, combined with temperature and humidity data from AIRS/AMSU/MHS and MIMR will enable much improved understanding and better estimates of surface fluxes to be gained from EOS satellites. High temporal and spatial resolution information on convective cloud systems and upper tropospheric water vapor from GOES, GMS, and Meteosat are being used extensively. More detailed global data on cloud abundance, structure, and optical properties can be derived from instruments such as MODIS, CERES, and MISR, within EOS. Improved data on the abundance of tropospheric aerosols that may affect the radiation balance and influence cloud properties will be provided by EOSP and MISR, also on EOS. MLS and GLAS will provide unique information on upper tropospheric water vapor and thin cirrus cloud decks, respectively.

Participation in Field Programs

The investigators are involved in a number of field programs that are closely related to the goals of this investigation, such as TOGA/COARE, ASTEX, TRMM surface validation, and NSCAT ADEOS validation.

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Principal Investigator
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Dennis Hartmann received his Ph.D. in Geophysical Fluid Dynamics from Princeton University in 1975. He joined the faculty of the Department of Atmospheric Sciences at the University of Washington in 1977. His main research interests are in global climate, large-scale dynamics, the radiative energy balance of Earth, and stratospheric ozone. He has published over 80 refereed papers on these topics and has authored a textbook about global climate. Dr. Hartmann served as a Principal Investigator in the Earth Radiation Budget Experiment (ERBE) and the Airborne Antarctic Ozone Experiment (AAOE), for which he received NASA Group Achievement Awards. He is a Fellow of the American Meteorological Society and the American Association for the Advancement of Science and serves on numerous national and international service and advisory boards.

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Climate, Erosion, and Tectonics in Mountain Systems

Principal Investigator—**Bryan L. Isacks**

Science Background

For humans, the most dramatic effects of climate change will be felt where we live, on the land surface. This is particularly true for major mountain belts where climatic and tectonic processes combine to produce the Earth's highest rates of weathering and erosion. In these regions, landsliding, soil erosion, vegetation change, and catastrophic flooding all represent natural hazards that may be exacerbated in the future by climate change. These alpine regions are of major importance to downstream hydrology and provide most of the inorganic chemical loads for lowland river systems such as the Amazon or Ganges/Bramaputra. They also contribute a significant but poorly documented organic load from the transport of debris from landslides in mountain rainforests.

Earth's highest rates of weathering and erosion are largely confined to tectonically active mountain belts characterized by high relief, steep slopes, nearby earthquakes, and abundant precipitation. These energetic regimes are characterized by three major altitudinal zones: 1) a high-altitude alpine regime dominated by seasonal snow melt and glacier dynamics operating over seasonal-to-millennial time scales; 2) a medium-altitude alpine regime characterized by high relief, intense rainfall, landsliding, and a vigorous fluvial system also partly supplied by upstream snow and glacial meltwater; and 3) a low-altitude "foreland" region where some fraction of the rock and organic material derived from the mountain belt is stored.

In these alpine regions the interaction of tectonics and climate are closely coupled on a geologic time scale and together build the mountain landscape. However, on decadal time scales, the alpine system is dominated by large events rather than steady, slow change. Monsoons and other seasonal cycles, ENSO variations, large storms, persistent precipitation producing flooding, glacier dynamics, earthquakes, and landsliding, alone or in combination, account for most of the erosion and transport of material out of mountain belts. In different areas, different types of atmospheric forcings will be important for determining the distribution of erosion in time and space.

Science Goal

Our investigation strives to understand the interaction of climate and land surface processes in major mountain belts where these interactions are most dynamic and complex. By observing how natural climate and climate change affect hydrological and geomorphic processes, we will be better able to predict the effects of climate change on mountainous and adjacent lowland regions.

We plan to develop our improved understanding of the operation of these energetic alpine systems through 1) direct, real-time monitoring of changing land surface features together with correlated synoptic weather conditions, and 2) the development of models that can effectively integrate the observations and give insight into the operative physical mechanisms. By monitoring the climate system together with key observable features of the land surface, we can address the difficult problems of how atmospheric moisture is delivered to mountain belts in both time and space, and how this delivery affects the hydrological and erosional regimes.

Current Activities

We are using a combination of climate data, remotely sensed images, and digital topography to quantify hydrological and mass fluxes from various mountain belts as functions of both time and space. We are integrating these observations with atmospheric and hydrologic models to improve the physical understanding of these processes that is required for more-refined prediction of the future effects of climate and land use changes in mountainous regions.

Dramatic examples of natural climate change abound in the geologic record, with the most obvious occurring at the conclusion of the last glacial period, about 15,000 years ago. An important aspect of our current research is identifying the climatological effects of the last glacial maximum (LGM) in the Andes and Himalaya, and identifying the geomorphic results of rapid deglaciation following the LGM. The climate fluctuations of the latest Pleistocene and early Holocene may provide important clues as to how global climate change occurs in mountainous regions.

Mountain belts also exhibit sensitive indicators of modern climate change. We are acquiring available sequential observations of indicators such as glacier termini and facies, snow lines, and lake levels to provide information on changes that have occurred during the past several decades and to provide baseline data for future changes.

Use of Satellite Data

With the beginning of EOS AM-1 observations in 1998, our project will consist of three main components: long-term monitoring, event monitoring, and modeling. The first will concentrate on establishing baseline observations and observing gradual, seasonal-to-decadal scale changes in the land surface for selected key regions of the Andes, the Himalaya, Alaska/British Columbia, and possibly others. The identification of key regions and development of baseline data are being developed with pre-EOS and EOSDIS Pathfinder data. Our focus on the Andes provides headwater information for other IDS investigations focusing on the Amazon lowlands. With MODIS, MISR, ASTER, and ancillary SAR data, we will quantify rates of glacier retreat, rates of vegetation change, frequency of landslides, changes in lake levels, and the amount and type of snowcover. More frequent, targeted observations with ASTER and SAR will allow us to obtain long-term discharge and suspended load concentrations in particular rivers. These observations can be continually related to root atmospheric causes through integration with 4D assimilation climate models as well as TRMM and MODIS precipitation and cloud data.

To investigate the role of short-term events in shaping the landscape, we intend to “catch” storm events and earthquakes by monitoring 4-D data assimilation models, daily MODIS and MISR images, data from existing weather satellites, and on-line earthquake reports. Having identified a major event, we can make rapid, targeted observations with ASTER (with ancillary SAR and Landsat TM images) to identify the direct results of the event on the land surface.

Participation in Field Programs

The geographic scope of our project necessitates close cooperation with local researchers, both to verify satellite data with ground truth, and to collect historical hydrologic, climatologic, and geologic data. We have worked extensively in Bolivia with the Bolivian Asociacion Boliviana de Teledeteccion para el Medio Ambiente (ABTEMA) and French L’Institut Francais de Recherche Scientifique pour le Development en Cooperation (ORSTOM) research groups as part of NASA SIR-C and AIRSAR campaigns and in Argentina with local geologists and hydrologists. In British Columbia we have access to Canadian hydrological data and have provided an extensive temporal set of ERS-1 SAR data for the Iskut River and associated glaciated headwaters. In 1995, we are developing contacts for ground data for the Nepal Himalaya and Patagonia.

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Bryan 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, Director of the Institute for the Study of the Continents, and Chairman of the Department of Geological Sciences. Since the late 1980's, Dr. Isacks has concentrated his major research efforts towards the exploitation of satellite remote sensing and digital topographic data to the understanding of surface processes in mountain belts. Dr. Isacks, together with other EOS team members at Cornell, is initiating a new Cornell inter-college undergraduate major in the Science of Earth Systems.

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

Principal Investigator—**Yann Kerr**
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Science Background

Remotely sensed and other data distributed by EOS will allow scientists to monitor changes in hydrologic fluxes due to a variety of forcings. When coupled with robust hydrologic models, a better understanding of the processes that control changes in hydrologic storages and fluxes is possible. This knowledge will allow scientists to better assess the role of the hydrologic cycle in a global context and to predict the effects of natural climatic or human-induced change. Such information is particularly critical in the southwestern U.S. and in Sahelian Africa, where the quality of life and agricultural productivity are especially sensitive to changes in the hydrologic cycle and where space-based remote sensing is particularly effective.

Science Goals

The major objective of this research is to monitor and study the hydrological cycle and climatic processes in arid and semi-arid areas with the use of EOS data applied to temporally and spatially distributed models. Consequently, the major questions that this research seeks to address are related to: hydrologic process dominance and scaling; the spatial and temporal distribution of surface energy and water fluxes; estimation of hydrologic variables using EOS remotely sensed data; validation of EOS observations and products; improving land-surface hydrologic models; and the role of soil moisture. Our strategy is to approach similar problems from different time and space scales and at different levels of model complexity in order to find the most robust and accurate description of the hydrologic cycle across the world's vast arid/semi-arid regions.

Current Activities

The intent of our research is to improve greatly the human ability both to monitor and to simulate land-surface hydrologic processes across a range of spatial and temporal scales. These two themes are being developed in parallel and are both critical to our success. Thus, one thrust is to develop algorithms that efficiently and accurately convert the electromagnetic signals obtained from EOS and other sensors into hydrologic parameters and variables. The other thrust is to develop an understanding of how fundamental hydrologic processes operate and interact with each other.

Our activities include the calibration and validation of optical, thermal, and microwave satellite data derived from simultaneous ground/satellite measurements across highly instrumented watersheds in the U.S., France, and the Sahel region of Africa. Other work focuses on the aggregation and disaggregation of model and observed variables at General Circulation Model (GCM) scales and the parameterization and coupling of land-surface hydrology models within GCMs. These activities are coordinated between two teams, one in France and the other in the U.S.

The French Team seeks to quantify and monitor natural and anthropogenically induced changes in hydrologically relevant surface parameters at meso-scales. Work performed to date has dealt mainly with investigating the extraction of geophysical parameters from remotely sensed data. First, sophisticated radiometric models are developed that include various perturbing factors (atmosphere, directional effects, canopy structure). After validation, these models are reparameterized to derive more tractable and robust inversion algorithms, which are subsequently validated using ground experiments. Similarly, flux assessment algorithms are being developed and tested. In order to assess CO_2 fluxes, net primary production models are being developed. They rely on vegetation growth models and thus couple water and energy budgets with generic vegetation models.

The U.S. team is focusing on understanding hydrologic processes at the sub-watershed and watershed scale and then expanding to basin and regional scales. Satellite data are used to derive distributed basin characteristics, as well as inputs to water/energy simulation models. Progress to date has been largely on 100 km^2 and smaller scale studies of hydrologic variability, satellite validation, and the effects of sparse desert canopies. Several hydrologic models have been developed, following a four-dimensional data assimilation approach to incorporate surface meteorological data, historical climatology, weather forecast data (National Weather Service Eta analysis fields), and off-line GCM land-surface models.

Use of Satellite Data

The hydrological sciences and the entire investigation team look forward to well-calibrated, atmospherically-corrected and georeferenced EOS-era satellite products to better characterize sparse canopies and soils (ASTER), seasonal vegetation and bidirectional reflectance (MODIS, MISR), radiation (CERES), and precipitation and soil moisture (MIMR). Equally important are non-EOS sensors operated by NOAA and ESA, particularly with regard to diurnal radiation, clouds, and active microwave measurements. We are involved at different levels in several EOS instrument teams (MODIS, MIMR, ASTER) as well as other instrument teams for satellite instruments (POLDER, VMI, TRMM) and for airborne instruments (MIRAS, PORTOS, ESTAR).

Participation in Field Programs

An important component of our research has been the organization and support of a number of field experiments. Most important is HAPEX-Sahel, which took place in 1991-1993, with an intensive observation period in 1992 over a GCM-size grid square. (HAPEX -Sahel is the Hydrologic Atmosphere Pilot Experiment in the Sahel.) The USDA-ARS Walnut Gulch watershed in Southeast Arizona has also been the focus of several field campaigns, where observations have been made at a range of scales (1-10000 km^2). Many of us have also been involved with other international initiatives related to global change such as IGBP and GEWEX.

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Yann Kerr received his Ph.D. from the Université Paul Sabatier, Toulouse, France, and his M.S. from Glasgow University, U.K.. From 1980 to 1985, he was with the Centre National d'Etudes Spatiales (CNES) in Toulouse. He joined the Laboratoire d'Études et de Recherches en Télédétection Spatiale (LERTS) when it was established in 1985. From 1987 to 1988, he took a leave of absence to work at the Jet Propulsion Laboratory in Pasadena, CA. He is currently head of LERTS. Dr. Kerr has worked mainly with the METEOSAT, Nimbus 7 Scanning Multispectral Radiometer (SMMR), ERS-1 Wind-scatterometer, and the Advanced Very High Resolution Radiometer (AVHRR) systems in order to improve the use of thermal infrared, microwave, and visible/near infrared data for assessing surface fluxes related to the hydrological cycle. He has been involved in several field experiments in Sahelian Africa, in the U.S., and in Europe. Dr. Kerr has served as a principal investigator on various projects and has helped organize the HAPEX-Sahel experiment.

Soroosh Sorooshian is professor and head of the Department of Hydrology and Water Resources and professor of Systems and Industrial Engineering at the University of Arizona in Tucson, AZ. He holds an M.S. in Systems Engineering and a Ph.D. in Water Resources Systems from the University of California-Los Angeles. 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 on numerous projects related to hydrologic modeling. He recently completed a four-year term as the Editor of *Water Resources Research*. He is serving on several national and international committees and is currently chairing the NRC's GEWEX Panel and the EOS Physical Climate and Hydrology Panel.

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Hydrologic Processes And Climate Interdisciplinary Investigation

Principal Investigator—**William K. M. Lau**

Science Background

The global water and energy cycles are integral components of the Earth's climate, providing linkages among the atmosphere, land, and ocean. In addition to supporting life on Earth, the presence of water plays a crucial role in the regulation of climate, through precipitation, evaporation, cloud generation, and moisture transport processes in the atmosphere; sea surface temperature regulation, salinity variation, and circulation of the oceans; and evapotranspiration, run-off, and storage processes on land. Rapid hydrologic events such as floods and droughts may lead to disastrous effects including loss of life and property and damage to the ecological system. Long-term changes in the global hydrologic cycle, natural or human-made, may lead to irreversible changes in the evolution of Earth's climate system, such as loss of arable land, desertification, rise in sea level and change in landscape.

Our present understanding of the inter-relationships among the above processes is inadequate. For better understanding of global climate change and the development of a sound scientific basis for policy recommendations, a knowledge of the inter-relationships among different components of the global hydrologic cycle is essential.

Science Goal

The goal of this investigation is to provide a description and a better understanding of the physical processes that contribute to the maintenance and variability of the global hydrologic and energy cycles. To achieve this goal, the investigation will focus on three closely linked scientific objectives aimed at improving understanding of the following: the physical mechanisms of atmospheric hydrologic processes (in particular, precipitation) and their interaction with the dynamics and radiative properties of the atmosphere; the role of hydrologic processes in large-scale ocean/atmosphere/land interaction leading to natural fluctuations of the global climate system over a variety of time scales; and the role of land surface processes (including storage) in the global hydrologic cycle, with emphasis on the integration and disaggregation between small- and large-scale processes.

Current Activities

Currently, the research tasks in this investigation are divided into four main thrusts: retrieval and algorithm development; global diagnostics and modeling; ocean/atmosphere processes; and land/atmosphere processes. Teams of Co-Is are focusing on the above thrusts. In particular, research tasks are aimed at the scale interactions among hydrologic processes in the land, ocean, and atmosphere in the tropics and mid latitudes.

Our team works with outside scientists through an exchange-scientist program. We actively participate in, and often serve as lead scientists in, a large number of national and international programs.

Use of Satellite Data

The investigation makes extensive use of data derived from current satellite platforms and (in the future) from EOS instruments. Results obtained from the pre-EOS observations are currently being used to provide a basic understanding of global and regional hydrologic processes through retrieval algorithm development, modeling, and data analysis. These activities in turn provide guidance for instrument design through the EOS launch phase. A synergistic approach based on analysis of data from space- and ground-based platforms is employed.

The investigation has designated liaison personnel to interact with the instrument teams on EOS and Earth Probe missions. Among the most critical instruments and satellite missions for this investigation are TRMM, CERES, MODIS, and AIRS/AMSU/MHS. A number of Co-Is will participate in the rainfall algorithm development in conjunction with TRMM, using both single and combined sensors satellites. Rainfall and latent heating profiles produced will be used by the modeling and diagnostic group to study hydrologic cycle variability and to validate model simulations. Microwave observations from MIMR will be used for atmospheric water vapor and soil moisture and evaporation studies. Total columnar and vertical profiles of atmospheric moisture and temperature from AIRS/AMSU/MHS will be combined with wind conditions to provide estimates of atmospheric moisture and heat transport. Data from MODIS and CERES will provide land surface and cloud information for retrieval of surface evapotranspiration and soil moisture.

Participation in Field Programs

We participate actively in programs such as the Global Energy and Water Experiment (GEWEX), the GEWEX Continental-scale International Project (GCIP), Global Precipitation Climatology Project (GPCP), International Satellite Land Surface Climatology Project (ISLSCP), International Satellite Cloud Climatology Project (ISCCP), First ISCCP Regional Experiment (FIRE), World Climate Research Program (WCRP), Atmospheric Model Intercomparison Project (AMIP), Atmospheric Radiation Measurements (ARM), and the Tropical Ocean Global Atmosphere (TOGA), and Coupled Ocean Atmosphere Response Experiment (COARE).

In addition to the above we are actively involved in the planning and execution and data analyses of field programs involving regional fluctuations of the water and energy cycle. These include Central Pacific Experiment (CEPEX), GEWEX Asian Monsoon Experiment, South China Sea Monsoon Experiment (SCSMEX), Tibetan Plateau Experiment (TPEX), Large Scale Atmospheric Moisture Balance of Amazonia using Data Assimilation (LAMBADA), and FIRE-III.

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William Lau received a Ph.D. in Atmospheric Sciences from the University of Washington in 1977. He was Assistant Professor at the Naval Postgraduate School until 1981. Since then he has been a Senior Research Meteorologist in the Goddard Laboratory for Atmospheres (GLA) at Goddard Space Flight Center. Currently, he is Head of the Climate and Radiation Branch of GLA. His research expertise includes empirical data analysis and modeling in climate dynamics, tropical and monsoon meteorology, and ocean-atmosphere interaction. He has published over 70 research papers in the refereed literature. He served as Chairman of the American Meteorological Society (AMS) Committee on Climate Variations, member of the U.S. Science Working Group for TOGA/COARE, chief scientist of the U.S.-People's Republic of China bilateral research on monsoons, and as a science team member of TRMM. He was awarded the AMS Meisinger Award and the NASA John Lindsay Memorial Award for excellence in research. Dr. Lau is a Senior Goddard Fellow and a fellow of the AMS.

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

Principal Investigator—**John Le Marshall**

Science Background

This investigation involves the development of processing algorithms and techniques to derive geophysical parameters of significance to atmospheric science from the Atmospheric Infrared Sounder (AIRS), Advanced Microwave Sounding Unit (AMSU), and the Moderate-Resolution Imaging Spectrometer (MODIS) instruments.

Science Goals

Developing a methodology to assimilate parameters into numerical weather prediction (NWP) models has received and will continue to receive strong emphasis, and an assessment of the utility of these data for NWP will be verified. In tandem, intercomparison studies will be performed with the satellite data, including the use of some special ground-based observations as appropriate. As a first step, researchers will derive sounding data from the AMSU radiances available in 1995/96; these data will be evaluated to determine the benefits provided to ongoing studies of the Southern Hemisphere. Concurrently, research will be directed at developing the local capacity for the simulation, processing, and utilization of data from AIRS and MODIS, and for assimilation of the EOS-processed data into Numerical Weather Prediction models.

Current Activities/Use of Satellite Data

Work to date has concentrated on two areas: AIRS synthetic data generation and geophysical parameter extraction and the processing and application of pre-EOS satellite observations. The pre-EOS data work has included the completion of a raw radiance-based retrieval scheme, now used operationally in the Australian Bureau of Meteorology (BoM), the testing of a new retrieval scheme incorporating AVHRR and TOVS, i.e., the testing of a MODIS/AIRS-type retrieval scheme, and recent work, generating and applying locally generated high spatial and temporal resolution cloud vector winds using both conventional and variational techniques, which involve the application of a forecast model and its generalized inverse. This variational technique appears to be well suited to the processing of cloud vector-wind data as well as high-resolution sounding data.

Participation in Field Programs

Field program work to date has consisted mainly of the collection and determination of geophysical parameters from local ground-based high-resolution radiance observations ($\Delta\lambda/\lambda$ = 1/1000 for ~ 4 to 15 μm.)

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Principal Investigator
John Le Marshall

John Le Marshall received a Ph.D. in Physics from Monash University in 1972. His areas of expertise include remote sensing and data assimilation. Current activities include land, oceanic, and atmospheric application of AVHRR and TIROS Operational Vertical Sounder (TOVS) data, and geostationary meteorological satellite data. He presently serves in the Bureau of Meteorology Research Centre in Melbourne, Australia, and is responsible for development and research related to satellite meteorology.

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

Principal Investigator—**W. Timothy Liu**

Science Background

The ocean is forced at the surface largely through the exchanges of water, momentum, and heat. Without surface forcing, the ocean would just be a static pool of water. The exchanges drive the transport and change the storage of heat, water, and greenhouse gases and thus moderate the world's climate. The ocean feedback to climate changes must be manifested through these exchanges, without which the Earth would be a hostile or less-suitable habitat. We need to study ocean circulation and air-sea exchanges to understand natural global changes and to discern the anthropogenic effects.

The ocean is an under-sampled turbulent fluid with non-linear interactions; processes at one scale affect processes at other scales. Adequate observations at significant temporal and spatial scales can only be achieved from the vantage point of space. A suite of complementary spaceborne sensors is needed to unravel the complex processes of the ocean-atmosphere interactions. Our study will demonstrate that the value of flying the suite of sensors together continuously (the essence of EOS) far outweighs the benefits of flying individual sensors one at a time. However, space-based observations alone cannot probe the deep ocean and *in situ* measurements are also needed. Ocean general circulation models have the potential of providing the dynamic interpolation and integration of these various data. Our study will take advantage of the recent advances in computer technology and the maturity of ocean general circulation models to assimilate the variety of data available during the EOS era.

Science Goal

The goal is to improve diagnosis and prognosis of global changes through the understanding of the coupled ocean-atmosphere system. The objectives are: 1) to improve existing and to develop new methodologies for estimating global ocean-atmosphere fluxes in momentum, energy, water, and carbon dioxide; 2) to study the changes in the transport and storage of heat, water, and greenhouse gases by the ocean in response to surface forcing; and 3) to understand the energy and hydrologic balances of the atmosphere and their relation with ocean surface fluxes.

Current Activities

The strategy of our investigation has evolved over time, but it is based largely on the synergistic and interdisciplinary approaches of applying satellite data, ground-based measurements, and numerical models to our research. Our current activities support our three objectives. We are improving the bulk parameterization method for estimating turbulent fluxes and deriving relevant parameters from satellite observations. We are developing a new methodology for estimating hydrologic forcing using satellite data, both through direct measurements and through a budget-residue technique. We have studied ocean surface momentum balance and wind-driven ocean circulation using Lagrangian drifters and wind speed data obtained by scatterometer. We are relating sea level changes to changes in both ocean dynamics and storage of heat and water. We have been studying how the cloud forcing, convection, and surface heat flux are related to sea surface temperature changes,at intraseasonal, seasonal, and interannual time scales.

Our modeling effort is focused on our eddy-resolving Ocean General Circulation Model (OGCM) with realistic thermodynamics. The surface forcing derived from satellite data is being used to force the OGCM, and the model responses are being compared with observations both from spaceborne and ground-based sensors. We will learn to interpret the differences in terms of specific physical processes and model weaknesses. Data assimilation techniques are being vigorously pursued, both for improving model performance and for interpolation and integration of data. We plan to extend our study to coupled ocean-atmosphere models in the future. Our efforts in satellite data application and ground-based measurements are described below.

Use of Satellite Data

Our team has strong experience in estimating ocean surface forcing using satellite data. We are currently using: SSM/I and AVHRR data to estimate evaporation and latent heat; International Satellite Cloud Climatology Project (ISCCP) data to compute solar irradiance; GPCP (Global Precipitation Climatology Project) data to provide rain amounts; and scatterometer (ERS-1) data to derive wind stress. We are also using sea level data from altimeters (Geosat and TOPEX) and sea surface temperatures (AVHRR) to study the ocean's dynamic and thermal responses. In the near future, we will continue to use data from operational sensors, e.g., AVHRR, TOVS, SSM/I, SSMT2 (humidity sounding), ISCCP, and GPCP; from scatterometers and altimeters on ERS-1 and -2; from SeaWiFs (ocean productivity); from NSCAT and OCTS on ADEOS; from TRMM; and from GLI and AMSR on ADEOS II. We are actively preparing for the improved accuracy and resolution of expected EOS sensors, such as, SeaWinds, Radar ALT (the ocean altimeter), MIMR, AIRS/AMSU/MHS, MODIS, and CERES at the turn of the century.

Participation in Field Programs

Our team members have a long history of participation in the design of *in situ* monitoring programs and the execution of field campaigns for the Tropical Ocean Global Atmosphere (TOGA) Program and the World Ocean Circulation Experiment (WOCE). We shall continue in the analysis of data from experiments such as TOGA/COARE (Coupled Ocean Atmosphere Response Experiment), and active planning of new programs such as the Global Drifter Program and the Atlantic Climate Change Experiment.

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Changes in Biogeochemical Cycles

Principal Investigator—**Berrien Moore III**

Science Background

This is an investigation of the primary biogeochemical cycles of planet Earth. Models of the Earth's biogeochemical cycles provide a rigorous means for developing quantitative projections of the interactions of atmospheric composition, climate, terrestrial and aquatic ecosystems, ocean circulation and sea level, and the effects of human activities. The family of models being developed in this investigation will provide the predictive link between the physical and biological Earth system and the human dimensions of global change.

Initial efforts focus on the cycles of water, carbon, nitrogen, and selected trace gases. Process-based models are being developed as modules, in concert with database management techniques which synthesize the *in situ* and remote sensing data needed to characterize regional and global scales. Ecosystem, hydrologic, and biogeochemical models will ultimately be coupled interactively to atmospheric chemistry and transport models. The results of this investigation will support the priority research needs of the Intergovernmental Panel on Climate Change (IPCC) and other regional and global integrated assessment activities.

Science Goal

The goal of this investigation is to understand how biogeochemical cycles function: 1) in quasi-steady-state systems determined by natural climate variability, and 2) in the transient states induced by human activities such as changes in land cover and use, and in emission of greenhouse gases. The team will develop regional-to-global scale, geographically specific, mathematical models and databases that describe the dynamics of water, carbon, nitrogen, and trace gas fluxes and reservoirs over seasonal-to-century time scales. This suite of models will rest within an interactive information system which couples remote sensing data and numerical models. The information management system is the link between Science Computing Facility of the University of New Hampshire EOS research team and the EOSDIS. It is networked into the World Wide Web and thereby makes data widely available to other scientists around the world and to policy makers.

The ultimate application of the global biogeochemical model developed in this investigation is to the design of scientific principles for achieving a sustainable future. The model components will also have specific applications to regional and national requirements for improved management of natural resources.

Current Activities

Current activities of this team are based on a hierarchical strategy, which builds from field to regional to continental to global scales. To date the investigation has produced more than 60 scientific papers, and has established numerous collaborative activities with other EOS Interdisciplinary Science (IDS) and instrument teams. Selected highlights of the ongoing research program include:

- The Terrestrial Ecosystem Model (TEM) is being refined to incorporate improved estimates of soil carbon along gradients of temperature, moisture, and soil texture. Soil carbon is a critical component of the carbon cycle response to climate variability. TEM and our Denitrification-Decomposition Model (DNDC) are both being used to understand and quantify the effects of agriculture and carbon on nitrogen stocks and fluxes. These modeling studies interface directly with our remote sensing studies of land cover change in the tropics, and in temperate regions where there is large-scale agriculture. TEM is also being used in three model-intercomparison projects, two at the global scale and one at the regional scale.

- Progress towards a global water cycle model continues with the implementation of a Water Transport Model, which is coupled to our Water Balance Model. A global river-routing scheme at 0.5 degree resolution is combined with selected site information for test and evaluation. The model will be used in conjunction with the 1997-98 international South American field campaign, in which NASA will be significantly involved.

- Major progress has been made in developing global land cover databases in support of modeling studies. Version 0 products from satellite data include a comprehensive global dataset from daily acquisitions of AVHRR 1-km data, which are being used to develop the first accurate global land cover digital database. The data will also be used as a basis for fire detection. This dataset is being developed in close collaboration with researchers on other IDS teams and the staff of the Land Processes (LP)-DAAC. There is close cooperation with the International Geosphere-Biosphere Program's (IGBP) Data and Information System. In addition, a sample dataset based on high-resolution satellite imagery from platforms such as Landsat, SPOT, ERS-1, and JERS-OPS is being acquired by our team in collaboration with other EOS scientists. The high-resolution data will be used for calibration and eventual validation of the land-cover classification scheme being developed with the LP-DAAC.

- Working collaboratively with the NASA/NOAA Pathfinder Program, as well as scientists on the Brazilian IDS team, we have developed the first large-scale assessment of deforestation and secondary regrowth in the Brazilian Amazon using over 500 individual Landsat MSS and TM scenes. These results have significantly changed our understanding of deforestation in the critically important tropical forests; rates of clearing appear to be 4-fold lower than some previously published estimates and a large fraction (30%) of the these areas are being abandoned to secondary succession.

- In addition to detailed high-resolution analyses of forest changes in the Amazon basin, the project is completing, under the Pathfinder Program, the first detailed satellite assessment of land-cover change dynamics for the Indochina peninsula.

- At local-to-regional scales progress continues on the evolution of the Photosynthesis Evapotranspiration Model (PnET). This effort is designed to provide high-resolution estimates of the effects of climate change and atmospheric deposition on the carbon, nitrogen, and water balances of forest ecosystems at regional scales. PnET has been validated for 10 temperate and boreal forest ecosystems and is now being tested against regional stream-flow data sets. The full monthly version of this model has been run at a 1-km scale for the northeastern United States.

- The University of New Hampshire-Earth-Oceans-Space (UNH-EOS) team contributed significantly to the successful completion of NASA's Accelerated Canopy Chemistry Program. The main thrust of this program was to determine the potential for the measurement of total ecosystem canopy lignin and nitrogen concentrations, and from them the estimation of rates of important ecosystem processes, by high-resolution remote sensing. Results include the first successful two-scene calibration for both lignin and nitrogen, and the application of the resulting nitrogen data to a simple model for the estimation of total net carbon fluxes over the entire Prospect Hill tract at the Harvard Forest.

- The trace-gas team has assembled a detailed regional assessment of methane sources for the northeastern United States. This research effort is an integrated modeling, field measurement, and database management activity. Models of individual sources are implemented with inputs of key driving variables derived from a geographic information system, e.g., climate, carbon stocks, etc. The derived methane fluxes are returned to the Geographic Information System (GIS) and displayed in map format to identify the spatial scales of emission sources. These products are being developed to guide future space observations of tropospheric trace gases by MOPITT and TES.

- Participants at the Oak Ridge National Laboratory (ORNL) and the University of Virginia (UVA) are developing a global terrestrial carbon cycling model for analyzing responses to disturbances such as land clearing and fire. In order to contend with the spatial variability imposed by disturbances, an area distribution function is incorporated into a compartment model of ecosystem carbon cycling.

Use of Satellite Data

Investigators have been actively using existing satellite data and developing new applications for planned EOS satellite datasets. The global mapping of tropical deforestation uses large amounts of Landsat data (over 500 Gigabytes) acquired from ground stations all over the world. In addition SPOT, IRS-1, JERS-OPS, and MOSS data have been used for land cover studies. Synthetic Aperture Radar (SAR) data from ERS-1 and JERS-1 are being used to develop new techniques for land cover change analyses in regions which are heavily and regularly covered by clouds. In addition, the team is using SAR data to develop methods for monitoring and measuring the age of secondary growth, and as a tool for remotely assessing biomass accumulation in secondary growth in tropical forests. Experimental use of SIR-C data for characterizing secondary suc- cession has also begun.

The team has been using AVHRR data, both LAC and GAC formats, for land cover mapping. We have developed a new technique for analyzing multi-temporal AVHRR data using Fourier transformations of the Power Density Spectrum to map land cover in large areas such as Brazil and North America. These results are paving the way for future global land cover mapping using both the AVHRR Pathfinder dataset and the IGBP/LP-DAAC 1-km AVHRR dataset. The AVHRR-derived land cover datasets are then being coupled to numerical models of biogeochemistry and forest productivity in South America and North America. These efforts will provide valuable insights into ways to use MODIS data after the launch of the AM-1 platform.

Remote sensing data are being used as part of our hydrology research. SMMR-SSM/I passive microwave 37 GHz horizontal/vertical polarization temperature differences are being used to infer the dynamics of large river systems, specifically the magnitude of discharge and the onset and duration of floodplain inundation. AVHRR-NDVI data are used in continuing analysis of the distributed water balance of the globe. We are exploring the relationships between AVHRR-NDVI and intra-annual variations in water cycle elements, with an emphasis on seasonal evapotranspiration across different land covers.

Participation in Field Programs

Field research supplements and supports our global modeling research. We are actively participating in the planning for a major multiple-sensor campaign in the Brazilian Amazon, where both airborne and satellite remote sensing will be valuable inputs into process models of biogeochemistry in this important tropical biome. The team members have been long-standing participants in all of the Global Troposphere Experiment airborne measurement campaigns, and this work will continue to provide important data and process-level understanding for our research in global atmospheric chemistry. Team members have been involved in various SAR field programs, including the DC-8 deployment over South America, SIR-C, and the upcoming Radarsat activities. The team has been actively involved in all of the BOREAS field programs, which aim at understanding the role of boreal forests in global change.

In addition to these program-wide airborne and satellite remote sensing-based field campaigns, the team has developed its own field measurement activities throughout the world. The Landsat deforestation measurements made under the Pathfinder Program involve 22 field calibration sites throughout South America, Africa, and Southeast Asia. Researchers have logged hundreds of hours of field work in these tropical systems developing calibration and validation datasets, as well as making important measurements of canopy conditions and vegetation biomass.

Researchers have made extensive ground measure-ments in the course of their work with high-spectral-resolution sensors, such as AVIRIS. Coupled to these sensor-based measurements, team members have developed field measurement programs in the LTER sites, particularly the Harvard Forest; these measurements are being used to develop forest productivity models which will have global applicability with the launch of AM-1.

Team members have developed a set of field stations in the Brazilian Amazon. Continuous measurements of trace gases and soil carbon are made along a chronosequence of sites which have been cleared for agriculture. This program has focused on using ground-based measurements in conjunction with remote sensing and GIS data to develop process models of trace gas dynamics in tropical forest ecosystems disturbed by humans.

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Landsat Pathfinder URL:

http://pathfinder-www.sr.unh.edu/pathfinder/

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

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A Global Assessment of Active Volcanism, Volcanic Hazards, and Volcanic Inputs to the Atmosphere from EOS

Principal Investigator—**Peter J. Mouginis-Mark**

Science Background

The impact of volcanoes on the Earth system was dramatically demonstrated by the eruption in 1991 of Mt. Pinatubo (Philippines), and in 1994 by activity at Rabaul volcano (Papua New Guinea). Mt. Pinatubo has had a near-global effect via the introduction of 20-to-30 megatons of sulfur dioxide and aerosols into the atmosphere, and represents the second largest eruption this century—second only to Mt. Katmai (Alaska) in 1912. The materials injected into the stratosphere by Mt. Pinatubo circled the Earth in only 3 weeks, and covered ~42 percent of the Earth's surface after only 2 months. Atmospheric models suggest that a global cooling of 0.5 degrees Celsius took place the year after the eruption. In Papua, New Guinea, the hazards associated with volcanoes were clearly demonstrated by the unexpected eruption of Rabaul, which caused 30,000 people to be hastily evacuated hours before over a meter of ash was deposited in parts of the town of Rabaul!

The degassing history of a lava flow or an eruption plume may have a major effect on the local or hemispheric climate, depending on the rate of eruption, the magma chemistry, and pre-eruption storage characteristics of the magma. Through the analysis of ongoing eruptions, data from EOS surface imagers and atmospheric instruments are expected to significantly improve the understanding of volcanic hazards, how volcanoes work, and the short-term effects that eruptions have on weather and climate.

Science Goals

This investigation's objectives are three-fold: 1) to understand the physical processes associated with volcanic eruptions; 2) to investigate the manner by which sulfur dioxide, water vapor, carbon dioxide, and other volcanic gases are injected into the troposphere and stratosphere; and 3) to place the diverse volcanic eruptions into the context of the regional tectonic setting of the volcano.

Current Activities

Our major activity is the development of robust algorithms that enable us to routinely study volcanic phenomena and their impact on the atmosphere. This includes a wide range of investigations, including the development of SO_2 retrievals using UV and thermal infrared data, the mapping of topography and topographic change using radar interferometry, the analysis of the particle size distribution and gas content of volcanic eruption clouds, and the analysis of the distribution of temperatures within active lava flows. Automated techniques are also being developed that will detect a new eruption and, in the case of a thermal alarm, distinguish an eruption from a forest fire or other hotspot, thereby enabling event detection to be routinely conducted worldwide. Field programs that test the ability of remote sensing instruments to make quantitative measurements of volcanic phenomena, and the validation of satellite observations made at visible, infrared, and microwave wavelengths also make up much of our on-going research.

Use of Satellite Data

This investigation will draw heavily on many of the EOS sensors, combining high-spatial-resolution images of near-vent activity and daily regional low-resolution views of volcanic thermal anomalies and eruption plume dispersal. ASTER and MODIS will be used for temperature measurements of active lava flows and eruption plumes. TES, MLS, MISR, EOSP, and SAGE III will be used to study the dispersal of different volcanic gases and aerosols. ASTER and orbital radars (Radarsat 2, ENVISAT's ASAR) will be used for high-resolution topographic mapping of volcanoes and the analysis of ground deformation due to intrusions and eruptions. MODIS, GLAS, and MISR will be used to determine the height of eruption plumes and their three-dimensional shape, and these measurements will be compared to AIRS atmospheric temperature data in order to investigate eruption-plume dynamics.

Before the EOS satellites are launched, the team is using analog data sets from existing instruments, including AVHRR, ERS-1, HIRS, MLS/UARS, SIR-C/X-SAR, TOMS, TIMS, and TOPSAR. The radar data sets from ERS-1, SIR-C/X-SAR, and TOPSAR provide baseline topography for individual volcanoes which can be compared to future EOS digital elevation models derived from MISR and ASTER. Different orbital radar instruments are being used to gain experience in studying temporal changes on volcanoes. ERS-1 and SIR-C/X-SAR data are also being used to develop experience in handling large volumes of data and in working with on-going missions. HIRS is used as an analog for MODIS, and TIMS is an aircraft instrument similar to the thermal-infrared portion of ASTER, and is being used both for temperature studies as well as the development of algorithms for mapping tropospheric SO_2. Two versions of TOMS have been flown on satellites since 1978 and have been routinely used to estimate amounts of SO_2 released by volcanic eruptions. The MLS on UARS (Upper Atmosphere Research Satellite) is providing experience in the interpretation of daily global maps of SO_2 that start 3 months after the eruption of Pinatubo.

In order to observe eruptions while they are in progress, this EOS investigation will contribute significantly to the development of a near-real-time response capability. Automatically-generated alarms for hot lava flows will be produced continuously from the MODIS data stream. Such a capability is expected to be of benefit to numerous other studies of transient phenomena, particularly forest fires. Higher order data sets that document the characteristics of specific eruptions, the dispersal of eruption plumes, and the geology of individual volcanoes will be the primary archival products. These products will be transferred to the EOS Data and Information System (EOSDIS) and also maintained locally for access by the volcanology community at large.

Participation in Field Programs

Our team is heavily involved in several field programs related to the analysis of the 15 International Decade Volcanoes, as well as on-going studies of other active volcanoes around the world. We helped organize Decade Volcano Workshops at Santa Maria (Guatemala) and have a workshop planned at Taal (Philippines) in late 1995. Planning is underway to collaborate with the Japanese in the study of Mt. Unzen (Japan) and Mauna Loa (Hawaii). We have also experimented with the use of Fourier Transfer and other thermal IR sensors to monitor SO_2 and HCl at Mt. Etna (Sicily). In 1993, we participated in the NASA aircraft deployment to Kamchatka (E. Russia) to map some of the volcanoes and perform gas studies. These programs are multi-disciplinary, involving the measurement of volcanic gases, surface temperatures, ground deformation, and topography. Mapping, using satellite and aircraft data, is also conducted in the Andes of Chile and the Galapagos Islands, while synoptic radar data are employed to study volcanoes in the Alaska/Aleutian arc.

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Principal Investigator

Peter J. Mouginis-Mark

Peter Mouginis-Mark received his training in environmental sciences (Ph.D. from Lancaster University, England, 1977). He 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 now serves as Associate Director of the Hawaii Institute of Geophysics and Planetology. Dr. Mouginis-Mark has been actively involved in many NASA and foreign Earth orbital missions, particularly in the field of radar remote sensing. He is currently the Chair of the Commission on Remote Sensing of Volcanoes for the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI), and is a member of NASA's Earth System Science and Applications Advisory Committee (ESSAAC). He also has a strong commitment to space science education, is Director of the Hawaii Space Grant Consortium, and heads the EOS SEC Education and Outreach Panel.

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INVESTIGATION OF THE ATMOSPHERE-OCEAN-LAND SYSTEM RELATED TO CLIMATE PROCESSES

Principal Investigator—**Masato Murakami**

Science Background

It has been widely recognized that the observed long-term, climatic variations should be understood in the framework of an integrated atmosphere-ocean-land system. The atmosphere, ocean, and land interact with each other through the exchanges of heat energy, momentum, and water substance, while each subsystem undergoes changes following its own internally determined physical processes. One example can be seen in the relationship between the tropics and the global climate. The tropics act as heat source regions which drive the global atmospheric circulation. Recent observational and theoretical studies have revealed that the long-term variations of tropical heat sources play an important role in the climatic variability of the global atmospheric circulation, e.g., such phenomena as El Niño and the Southern Oscillation (ENSO).

The atmospheric circulation changes affect the oceanic circulation through the changes in wind stress at the sea surface. On the other hand, it is also known that the variations of the tropical heat sources are closely associated with the variations of sea surface temperature (SST) through the process of heat exchange. In addition, the circulation changes also cause changes of the soil moisture and snow cover over land. Recently, investigations have shown increasing evidence that changes in land surface conditions affect the variation of the large-scale atmospheric circulation features such as monsoons.

The preceding discussion serves to illustrate the importance of our understanding of the integrated behavior of the Earth system. There are other important components to be taken into account when we try to understand and predict climatic changes. For instance, the effects of atmospheric minor constituents on the global climate should be investigated by both observational and modeling studies.

Science Goal

The goal of this investigation is to perform a comprehensive investigation of the atmosphere-ocean-land system by pursuing seven different subjects (described in the next section) including both observational and modeling studies.

Current Activities

This investigation provides a mixture of observational studies and climate modeling related to the atmosphere-ocean-land interactions that occur through heat and momentum exchanges. The investigation has three components. First, researchers will develop algorithms for the objective identification of cloud types and the quantitative measurement of precipitation. Data validation of newly developed remote-sensing techniques will also be carried out. Based on these products, observational studies will be conducted to examine the atmospheric systems associated with various rainfall activities. The role of atmospheric minor constituents in climate changes will also be examined. Secondly, researchers will monitor climatic changes of the sea surface temperature, sea level, and sea surface wind through the use of satellite observations, eventually generating data sets that can be incorporated in the ocean modeling study of seasonal/interannual variations of the Pacific and the mid-latitudinal eddies of the ocean. Finally, researchers will examine land surface conditions, such as ground wetness and snow mass.

An atmospheric general circulation model (GCM) will be incorporated to evaluate the impact of anomalous surface conditions on climate change. Project elements will exchange results and data with other elements under the direction of the Principal Investigator to ensure overall understanding of the Earth system.

The seven supporting studies being conducted by the Meteorological Research Institute (MRI) of the Japan Meteorological Agency (JMA) are as follows: 1) measurement of precipitation and analysis of rain-producing systems; 2) study of the climatic and environmental changes affected by the increase of greenhouse gases; 3) ozone chemistry; 4) validation of EOS data by use of MRI lidar and JMA data; 5) monitoring of the ocean from satellites; 6) ocean modeling study; and 7) analysis of the changes of surface conditions in the vicinity of Japan, and studies of their impact on atmospheric circulations with the use of the MRI GCM.

Use of Satellite Data

In the atmospheric part of this study we plan to delineate the convective activity (heat sources) and moisture field at relatively fine spatial resolution with the combination of data from AIRS, MODIS, and MHS. We have been using AVHRR to estimate rainfall from cumulus-type clouds. The technique uses classification by the split window technique in conjunction with radar and rain gauge observations. The technique will be tuned to retrieve total precipitable water from the split window and passive microwave data, comparing results with radiosonde observation data. We will also intercompare the passive microwave retrieval and split window retrieval methods for rainfall estimation and also for water vapor estimation over cloud-free regions. During the early stage of EOS, intercomparisons with AIRS, ASTER, MODIS, MHS , and MIMR will be carried out. In the oceanic part of this study, efforts will be concentrated in developing algorithms for retrieving and validating the following geophysical parameters: SST, sea level, and latent heat flux. Algorithms for retrieving SST with MIMR will be developed.

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Principal Investigator
Masato Murakami

Masato Murakami was academically trained in Geophysics and Meteorology at the University of Tokyo, and earned his S. Sc. from that institution in 1974. Except for a 2-year position at Florida State University, Dr. Murakami has been affiliated with the Meteorological Research Institute for his entire professional career. Currently, he is Chief of Laboratory in the Typhoon Research Division. His research interests include tropical, monsoon, and satellite meteorology. He is acting as a WMO rapporteur on the Asian/African monsoon program and is engaged in the project management of JEXAM (Japanese Experiment of Asian Monsoon).

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

Principal Investigator—**John A. Pyle**

Science Background

The middle atmosphere is a highly coupled system in which dynamical, radiative, and chemical processes are intimately connected. CO_2 and O_3 play important radiative roles. Ozone absorbs ultraviolet radiation. This leads to a heating of the middle atmosphere and also protects the biosphere from a strong and potentially dangerous UV dosage. The distribution of ozone depends on the chemical interactions of a large number of other gases. Atmospheric temperature and the general circulation of the middle atmosphere are also crucial to determining the structure of ozone. Exchanges with both the troposphere and higher atmospheric levels are important in determining the longer term changes to the system. It is vital that all these processes be understood.

Science Goals

This investigation aims to improve our understanding of atmospheric dynamical, chemical, and radiative interactions—and hence the ability to predict and detect long-term atmospheric trends in the Earth's climatic and chemical environment. Modeling and data analysis efforts will focus on the following middle atmosphere and thermosphere components: 1) circulation and internally generated variability of the atmosphere; 2) interactions between chemical, dynamical, and radiative processes; and 3) horizontal and vertical coupling mechanisms.

The study will involve a two-pronged theoretical assault using EOS data and sophisticated numerical, dynamical, radiative, and photochemical models of the troposphere, stratosphere, and mesosphere now being developed in the United Kingdom.

Current Activities

As part of our study we have developed a hierarchy of numerical models of the middle atmosphere. These include two 3-D models. One is a free-standing general circulation model (GCM), based on a model from the European Centre for Medium Range Weather Forecasts, to which we have added a full description of chemical processes. The second is a chemical transport model in which the transport is specified, either from meteorological analyses or from previous GCM integrations. These models are complemented by a range of trajectory models of varying sophistication.

Our scientific studies have involved detailed investigations combining our models with atmospheric data. Thus a variety of UARS data sets have been studied using the full range of models. Particular investigations have looked at, for example, the descent within the polar vortex, the exchange between the polar vortex and middle latitudes, as well as studies of chlorine activation and deactivation.

Use of Satellite Data

Our EOS studies will involve the combination of our numerical models with various EOS datasets. Of particular interest will be instruments designed to measure chemical constituent concentrations or to provide dynamical or radiative information, especially for the middle atmosphere. These instruments include HIRDLS, MLS, TES, SOLSTICE, ACRIM, SAGE III, MOPITT, and CERES. The data will be used in a number of ways. Firstly, case studies of interesting periods will be carried out using our hierarchy of models. Secondly, seasonal, and longer, integrations will be performed, initializing the models with appropriate EOS data, and comparing the subsequent model and data evolution. Thirdly, in research mode, 4-dimensional variational assimilation studies will be carried out, building on studies currently underway.

Participation in Field Programs

We have participated in recent field campaigns such as: 1) EASOE - European Arctic Stratospheric Ozone Experiment; 2) SESAME - Second European Stratospheric Arctic and Mid-latitude Experiment; and 3) ASHOE - Airborne Southern Hemisphere Ozone Experiment

Of special interest have been very-high-resolution modeling studies to investigate the filaments of air, torn from the edge of the polar vortex, which have been observed and now successfully modeled.

These investigations are advancing our ability to combine data and models and so are paving the way to studies in the EOS era.

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Principal Investigator
John A. Pyle

John Pyle holds a D.Phil. in Atmospheric Physics from the University of Oxford. Since 1985, he has been a University Lecturer in Physical Chemistry at the University of Cambridge and head of the European Ozone Research Coordinating Unit since 1991. Currently, he serves as Principal Investigator in the U.K. Universities Global Atmospheric Modeling Programme supported by the Natural Environment Research Council. He has chaired the Core Groups organizing both EASOE and SESAME campaigns to study Arctic stratospheric ozone. 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 the recipient of the Eurotrac Award of the Remote Sensing Society.

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

Principal Investigator—**Richard B. Rood**

Science Background

This investigation will develop a research-quality, 4-dimensional atmosphere-ocean-land data assimilation system for EOS. The data assimilation combines all available data into a dynamically consistent depiction of the Earth-atmosphere system, and has the unique ability to produce estimates of unobserved quantities.

Data assimilation approaches are used throughout science and engineering. Most simply, data assimilation is the use of a mathematical-physical model to analyze observations, while at the same time quantifying the shortcomings of the model formulation. A classic example of the assimilation process is the parallel development of the theory of planetary motions and the discovery of the new planets. For example, the outer planets were hypothesized because a high degree of confidence was placed in the equations of motion, i.e., the model and new objects were needed to explain the observed perturbations in the orbits of the known planets. In traditional NASA culture, data assimilation techniques are crucial to orbit determination and were essential to navigation in the Apollo flights.

In Earth science, a data assimilation system is effectively an Earth-system model constrained by Earth-system observations. The practical aspects of this approach are enormous. The data assimilation system: 1) organizes the observations from many diverse instrument sources and measurement times into a single useful data product; 2) complements the observations by propagation of information from observed into unobserved regions and times; 3) provides estimates of expected values of the observations with which to assess data and instrument quality; 4) provides superior products for environmental assessment studies; and 5) supplements the observations by providing estimates of quantities that are difficult or impossible to observe.

Science Goals

The goals of this investigation are to produce an assimilation analysis to ensure that the maximum information is gained from the EOS and other observations, and to set the foundation for future Earth system models. Continual research into numerical and theoretical techniques and associated Earth science process studies will ensure that the developed system meets the needs of EOS. Analyzing historical and new data sets available in the pre-launch phase of EOS will serve as the initial basis to confront Earth system problems, and the successes and failures of these diagnostic and interpretive studies will define the evolution of the data assimilation system. The assimilated data produced in the pre-launch period will be made available to the broad science community to assure infusion of relevant diverse applications into the development process. A commitment is made to continued reanalyses of these data sets to minimize the impact of algorithm changes on interannual signals.

Current Activities

The investigation performs research into all aspects of 4-dimensional data assimilation, including satellite retrievals, data quality control, error propagation, objective analysis, and all component models of the Earth system. Data from satellites such as UARS, TRMM, and ADEOS will be used to assess the utility of new data types, such as wind and constituent data. Initial studies concentrate on meteorology, with an emphasis on the hydrological cycle and seasonal and interannual variability. Near-term development will emphasize land-surface and ocean-surface processes. A strong emphasis will also be placed on global transport processes and atmospheric chemistry.

Development schedule: The development of the EOS data assimilation system will proceed in 5 phases:

- *Phase 1 (1995)*—A prototype system will produce a 15-year (1979-1994) global gridded data set of meteorological and hydrological quantities. This version will use conventional meteorological and satellite observations. Its output will be distributed by the Goddard DAAC.

- *Phase 2 (1995-1997)*—The prototype version will be improved to accept new data from UARS, ADEOS, and TRMM, along with other sources such as the Pathfinder and COADS data sets. Analysis accuracy will also be improved through algorithms that take advantage of advances in computer hardware. Another reanalysis will be performed for 1979-1997.

- *Phase 3 (1997-1999)*—This version will accept the same data as the previous versions plus data from the AM-1 instruments. It will run operationally to provide "first guess" information for instrument retrieval algorithms. It will also be an independent quality control check for the EOS data. Another reanalysis will be performed for 1979-1999.

- *Phase 4 (1999-2001)*—This version will assimilate the same data as the previous systems plus data (especially AIRS data) from the PM-1 platform and from the AERO platforms.

- *Phase 5 (2001-2003)*—This version will assimilate the same data as the previous systems plus data from the CHEM platform.

Assimilation products to be made available include 4-dimensional gridded fields produced by the AM-1 version (Phase 3) including:

- *Atmosphere*: wind, temperature, moisture, geo-potential, turbulence, radiative heating/flux, clouds (amount, type, mass flux, and detrainment), precipitation, sensible and latent heat flux, and planetary boundary layer depth.

- *Surface* (*land and ocean*): albedo, temperature, pressure, evaporation, roughness (drag and wind stress), snow depth, soil moisture, and vegetative moisture.

- *Surface (ocean only)*: salinity, currents, sea state, and sea level height.

Participation in Field Programs

Near-real-time products from this system are used to support field programs such as SPADE, ASHOE/MAESA, ATLAS, STRAT, LAMBADA, etc. Participation in these campaigns is valuable for both system development and mission science.

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Richard Rood obtained a Ph.D. in Meteorology from Florida State University in 1982. Since then, he has been at NASA's Goddard Space Flight Center (GSFC). He has been involved in the development of atmospheric general circulation models, and three-dimensional chemistry and transport models. He has pioneered the use of winds and temperatures derived by data assimilation to study atmospheric transport processes. In 1992, he was appointed Head of the Data Assimilation Office at GSFC—the only center of data assimilation research that is not maintained within an operational weather forecasting center. The Data Assimilation Office produces research-quality data sets to study Earth system processes and global change.

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

Principal Investigator—**D. Andrew Rothrock**

Science Background

POLES is an investigation of the exchange of energy in polar regions, both at the air-ice-ocean interface and with lower latitudes, and of the role these processes play in global oceanic and atmospheric circulation. Even though fluxes are parameterized in a variety of ways in climate and general circulation models (GCMs), these models uniformly predict that the largest response to changing atmospheric carbon dioxide will occur in polar regions, a phenomenon referred to as "polar amplification."

Except for estimates of ice concentrations from passive microwave radiometers, most satellite data in polar regions were vastly under-utilized at the time of POLES inception in 1991. The polar research community depended mainly on climatological values for the central Arctic and simple parameterizations to force their models, which precluded simulations of regional and interannual variability.

Science Goal

Our purpose is to assimilate a rich array of observations into polar ocean-atmosphere models, not only refining the treatment of surface exchange processes, but also quantifying the roles of horizontal transports, oceanic mixing, and deep convection. With better use of data, we can move beyond the present climatological descriptions, based on sparse observations, and document interannual variability which is crucial to understanding whether polar regions show any sign of climate change.

Current Activities

POLES addresses these goals along three avenues: 1) by developing, assessing and improving satellite algorithms in polar regions; 2) by producing multi-decadal polar data sets of cloud and atmospheric properties of the sea ice state and of ocean behavior; and 3) by modeling polar processes in the combined atmosphere-ice-ocean system.

Satellite Algorithms—POLES has addressed weaknesses of polar satellite data by working on the special problems of algorithms and retrievals in polar regions. We have improved algorithms for TOVS and for AVHRR, showing how to account for the bright cold surface underlying clouds and how to retrieve useful estimates of cloud and surface properties, and atmospheric profiles. We have shown how to estimate boundary layer stability from TOVS for turbulent flux calculations.

Our algorithm work has been directed towards providing a long-term data set of surface fluxes and surface variables from existing sensors. Models and algorithms for the retrieval of surface and cloud properties using AVHRR data have been combined into an integrated program and toolkit called the Cloud and Surface Parameter Retrieval (CASPR) system. Other activities include the assimilation of passive microwave data into an ice model by Kalman filtering, and development of ice-tracking techniques that are now providing routine ice motion data from ERS-1 SAR satellites. We are also pursuing the measurement of ocean winds right up to the ice edge.

Data Set Production—We are committed to producing large-scale, long-term data sets that can be used by the research community as standards for various polar variables long listed by the polar community as necessary for process studies and model development. These include radiative and turbulent surface heat fluxes, cloud properties, surface temperature and albedo, sea ice concentration and ice thickness distribution, sea ice motion, ice melt and growth, and surface brine flux. These quantities serve as valuable resources for research in polar meteorology, sea ice dynamics and thermodynamics, and ocean modeling. We have produced data sets of sea ice motion, of surface radiative fluxes with data from the International Satellite Cloud Climatology Program, and of surface temperature from buoy and land and drifting station records. In cooperation with the TOVS Pathfinder team, we have produced a 20-month record of Arctic temperature and moisture profiles.

Modeling and Analysis—Our goal is to bring together a unified model of the lower troposphere, the sea ice cover and adjacent ocean surface, and the high-latitude ocean. Unlike a predictive GCM driven only by solar input and free to represent physical processes completely internally, our model is driven by as many observations as possible, such as cloud properties and downwelling radiative fluxes, and ice motion and concentration.

Our atmospheric modeling has addressed radiative and turbulent heat fluxes and horizontal advection of heat from mid-latitudes. Our radiation model computes surface radiative fluxes from atmospheric and cloud parameters, and our surface turbulent flux model includes effects of surface roughness and stability.

Sea ice behavior computed by assimilating ice motion and passive microwave satellite data is used to force the surface of an ocean model. We find very large interannual variations in the sea ice and freshwater exported through the Fram Strait. The mid-1980s were a period of low freshwater export; this corresponds with a low salinity anomaly in the Greenland Sea seen in analyses of ocean cruise records. These anomalous periods are believed to repress deep convection in the Greenland Sea and act as a control on the global thermohaline circulation in which the Greenland Sea is a crucial link. Outputs from our combined model will allow us to investigate the sites of formation of water masses and the pathways by which they mix or convect to lower levels of the ocean.

Use of Satellite Data

POLES will use data from a number of EOS and other new instruments, in continuation of our present assimilation of satellite data into models. For quantifying the interactions between the polar troposphere and the surface, we will use AIRS, AMSU, and MHS. We will utilize ice surface properties obtained from MIMR, MODIS, and MISR, ice motion from Radarsat and MODIS, and ocean winds from SeaWinds.

Participation in Field Programs

We require field data to test our satellite-based estimates of surface radiative and turbulent fluxes and surface properties such as temperature and albedo. In April 1992, we participated in aircraft flights over sea ice as part of LEADEX, the Lead Experiment, in the western Arctic Ocean. We will use the year-long field experiment, SHEBA, Surface Heat Balance of the Arctic, beginning in 1997 to improve our treatment of clouds and their radiative properties.

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Andrew Rothrock earned his Ph.D. from the University of Cambridge in 1968, studying fluid mechanics. Since 1970, he has been affiliated with the University of Washington, where he is a Principal Research Scientist in the Applied Physics Laboratory, and an Associate Research Professor in the School of Oceanography. His research interests include sea ice dynamics and kinematics, and the remote sensing of polar geophysical processes with active and passive microwave, and thermal and visible satellite sensors. He is an investigator on ERS-1 and -2.

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Using Multi-Sensor Data to Model Factors Limiting Carbon Balance in Global Arid and Semiarid Land

Principal Investigator—**David S. Schimel**

Science Background

This investigation addresses the role of arid and semiarid lands in processes that affect the global environment, such as carbon balance and trace gas exchange, and their vulnerability to climate variability and change in terms of their vegetation structure and primary productivity.

Arid lands are important to substantial human populations, including those in the American west, and are globally important sources and sinks for important trace gases, especially ozone precursors. Our project focuses on this dual role of arid lands in global change: 1) effects of climate on productivity and soil quality, and 2) production and consumption of regionally to globally important trace gases.

Science Goal

The goal of the project is to develop techniques for inferring dry-land and rangeland ecosystem function, e.g., plant growth, nutrient cycles, and trace gas exchange, from remote sensing and modeling, and to develop and test *predictive models* for ecosystem function for dry lands.

Current Activities

Modeling activities now underway include continued development of a global ecosystem model (CENTURY), which simulates the coupled dynamics of carbon, nitrogen, other nutrients, such as phosphorous and sulfur, and the hydrological cycle. The dry-land components of CENTURY further simulate the population-level interactions of woody and herbaceous species (a process which significantly determines the human utility of arid and semiarid systems), their carbon balance, and trace-gas exchange. The model can be run independently of remote observations for use in predictive calculations. CENTURY can also be used with satellite-determined surface climate variables and satellite-driven values of absorbed photosynthetically active radiation. These data, along with information on vegetation structure, enable the user of CENTURY to calculate gross primary productivity and fractional allocation of carbon to storage pools having different turnover times.

Use of Satellite Data

Remote-sensing techniques are being developed to support CENTURY model applications. The techniques include determination of vegetation structure from spectral unmixing of TM- or ASTER high-resolution data as well as from temporal changes in AVHRR or MODIS reflectances. The above techniques are being developed in coordination with the AVHRR Land Pathfinder Project, and with the MODIS Team. The project is also developing remote sensing techniques for determination of vegetation interception of light, plant growth, and water use. The primary variables to be determined are fractional absorbed photosynthetically active radiation (*f*APAR) and leaf area index (LAI). The project is emphasizing the development of a bi-directional reflectance distribution function algorithm for inferring *f*APAR and LAI, as a complement to work on vegetation indices. This work is in coordination with the MISR and MODIS instrument teams and the AVHRR Pathfinder Project. Principal EOS products to be applied will include MODIS NIR and visible radiances and MISR bi-directional reflectance factors, plus 4-D assimilation results for surface climate, along with land cover data from Landsat/ASTER.

Participation in Field Programs

In support of modeling and algorithm development, the project has conducted, or collaborated on, a series of field studies. These have included studies in the U.S. rangelands (Colorado, Kansas, and Texas), studies in Inner Mongolia, China (in cooperation with the Academica Sinica), and current studies in African rangelands (Central African Republic and Republic of South Africa). These studies have supported the development of algorithms for *f*APAR, LAI, and fractional woody vegetation cover, and have provided data bases for further model development (trace-gas exchange, carbon storage) and evaluation (vegetation growth, seasonal leaf area, soil/carbon).

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David Schimel, who received his Ph.D. in 1982, and served as a National Research Council Senior Fellow at NASA/Ames Research Center in 1988-1989, is currently a Research Scientist at the Natural Resources Ecology Laboratory in Fort Collins, an Associate Professor in the Department of Forest & Wood Science at Colorado State University, and a Section Head in the Climate and Global Dynamics Division of the National Center for Atmospheric Research. He is an active member of the American Geophysical Union, ESA, SCOPE, IGBP, and IPCC (convening lead author, 1994 and 1995 Reports) as well as a participant in several science steering committees. In addition, he is a reviewer for nine journals, a panelist for NSF, and a consulting editor for three journals.

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Investigation of The Chemical and Dynamical Changes in The Stratosphere

Principal Investigator—**Mark R. Schoeberl**

Science Background

This interdisciplinary science investigation focuses on analyzing stratospheric and tropospheric chemical and dynamical changes using EOS instruments and current satellite and aircraft data sets.

Complex and subtle chemical changes are occurring within the Earth's atmosphere, mostly as a result of changes in the surface emission of important trace gases. This investigation is primarily interested in the response of ozone to these trace gas changes—changes in stratospheric ozone as a result of increasing human-made chlorine—and tropospheric ozone changes due to biogenic activity such as land use changes, industrial pollutants, and biomass burning. To separate natural changes in trace gases from those generated by human activity, high quality data sets are needed for analysis. Interpretation of the changes requires complex chemical models. In addition to analysis of the data, this investigation is responsible for the production and quality of chemical data products produced by the EOS Data Assimilation effort.

Science Goal

The scientific goal of the investigation is to isolate natural from anthropogenic chemical changes in the Earth's atmosphere to determine their effects on ozone and to assess radiative and dynamical feedbacks.

Current Activities

The data analysis effort supports the development and validation of models being created as part of this investigation, while the modeling effort supports interpretation of the data. There are three major activities within this group: model development, satellite and aircraft data analysis, and chemical assimilation/data set generation.

Model development—This investigation has developed two new models. The first is a fully interactive 2-dimensional chemical/dynamical model. This model is being used to examine the dynamical feedbacks associated with ozone loss and the impact of natural pollution events such as the eruption of Mt. Pinatubo. Because of the large computational cost of fully 3D interactive chemical models, the 2D interactive model is the only way we can currently examine the interaction between radiative feedbacks and chemical depletions.

We have also developed a Lagrangian Chemical Model which, along with the off-line 3D Chemical Model (partially supported under this investigation), is being used to investigate the evolution of the annual polar ozone depletions and to analyze aircraft observations. The experiment underway is to simulate the secular evolution of the Antarctic ozone hole through varying the chlorine amounts and introducing the meteorological variability.

Analysis of satellite and aircraft data—Our second major activity involves the analysis of satellite and aircraft data with regard to model validation and increasing our understanding of the chemical processes within the stratosphere. We are currently focusing most of our efforts on analysis of Upper Atmosphere Research Satellite (UARS) data and data from the Airborne Southern Hemisphere Ozone Expedition (ASHOE) experiment. We have, for example, developed a new technique to bring spatially separate observations together—this method called trajectory mapping removes the need for simultaneity in measurements of longer-lived trace gases and allows us to utilize meteorological constraints on trace gas measurements in an optimal way.

Analysis of the UARS data is especially important for this investigation since the UARS instruments, CLAES, ISAMS, and MLS are progenitors of the EOS CHEM instruments (HIRDLS, MLS). We also continue with our analysis of the TOMS data with respect to the size and variability of the polar ozone depletions. EOS CHEM will fly the Japanese-provided ODUS, which is similar to TOMS in measurement capability.

In addition to our satellite data analysis, we also are examining the data from the series of stratospheric and tropospheric aircraft expeditions in which we have participated. The aircraft data set provides us with a rigorous test of our models and analysis methods since the data generally have much higher precision than the satellite data and sample much smaller spatial scales. Our analysis of ER-2 data has contributed to an important breakthrough in understanding the origins of small-scale chemical features in the stratosphere.

Members of our team are also project scientists for two future stratospheric aircraft expeditions: STRAT and TOTE/VOTE (Tropical Ozone Transport Experiment/Vortex Ozone Transport Experiment) scheduled for 1995-7 timeframes. The STRAT expedition will be looking at the evolution of long-lived trace gases throughout the season, while the TOTE/VOTE mission will be examining small-scale features formed at the boundaries of the stratospheric polar vortex and the tropical barrier.

We have already been analyzing data from aircraft expeditions such as TRACE-A. Using the trajectory model developed by this investigation, we have been able to show that the mid-Atlantic tropospheric ozone anomaly results from South American biomass burning. This shows that we can use the trajectory transport technique in the troposphere as well as the stratosphere to understand the origins of pollutant episodes.

Chemical assimilation/data set generation—The third major activity of this investigation is the development of meteorological and chemical data sets for EOSDIS. Sixteen years of NMC global stratospheric data have been analyzed, and balanced winds and potential vorticity have been produced and are awaiting transfer to the Goddard DAAC. Under development is a chemical assimilation model which will directly assimilate satellite chemical measurements. Here we work in close collaboration with the EOS Data Assimilation Office (R. Rood, PI). We are responsible for stratospheric meteorological data quality and the quality control of the chemical assimilation system. We are currently using UARS data as a test of that system and have generated prototype data sets using UARS CLAES nitrous oxide measurements.

The EOS AM-1 MOPITT, and EOS CHEM TES instruments will provide important new information on the changing chemistry of the troposphere. The carbon monoxide and methane measurements from MOPITT will be used with our Lagrangian chemistry model to understand the dispersal of pollutants within the troposphere. Carbon monoxide is a medium-lived trace gas (life time of weeks) and how it is dispersed throughout the troposphere by pollution events provides clues to the origin of the pollution sources and the chemical renewal process. With the launch of the EOS CHEM TES instrument, the measurement range of tropospheric trace gases will be extended, and the analysis techniques we have applied to MOPITT carbon monoxide measurements will be extended to ozone, nitrogen, and sulfur oxides.

This investigation is also performing analysis of the observing strategies and spectral characteristics of the EOS instruments scheduled for launch. For example, our analysis of the fine-resolution atmospheric UV absorption characteristics showed that the SOLSTICE SURE option could be deselected. We are currently performing a study of the optimal way to utilize the HIRDLS horizontal scanning data. One of our team members (Gleason) is the EOS CHEM Project Scientist.

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(Go to the EOS room on the image map)

Principal Investigator
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Mark Schoeberl received his Ph.D. from the University of Illinois in 1976. He has 20 years of research experience in atmospheric dynamics, stratospheric physics, and numerical modeling. He is the author or co-author of more than 110 scientific papers. Dr. Schoeberl has been affiliated with NASA/Goddard Space Flight Center since 1983. He is also the Upper Atmosphere Research Satellite Project Scientist and heads the Atmospheric Chemistry and Dynamics Branch at the Goddard Space Flight Center. Within his field of research, he has chaired multiple conferences and committees, and has served in an editorial capacity for several journals. He is a recipient of the NASA Exceptional Scientific Achievement Medal and several NASA Group Achievement Awards. He is a fellow of the American Geophysical Union and has served as the first EOS Atmospheres Panel chairman.

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Biosphere-Atmosphere Interactions

Principal Investigator—**Piers J. Sellers**

Science Background

This investigation is directed at improving our understanding of the role of the terrestrial biosphere in global change using models, *in situ* observations, and satellite data. Specifically, the science investigations in the project cover both short-term (biophysics) interactions between the land biosphere and the atmosphere and long-term (ecology, anthropogenic impacts) interactions. Figure 1 shows how the processes associated with biophysics and ecological modeling overlap in the areas of primary production (photosynthesis), water relations (transpiration), and remote sensing (radiation). The expertise in the group spans the range of science issues depicted.

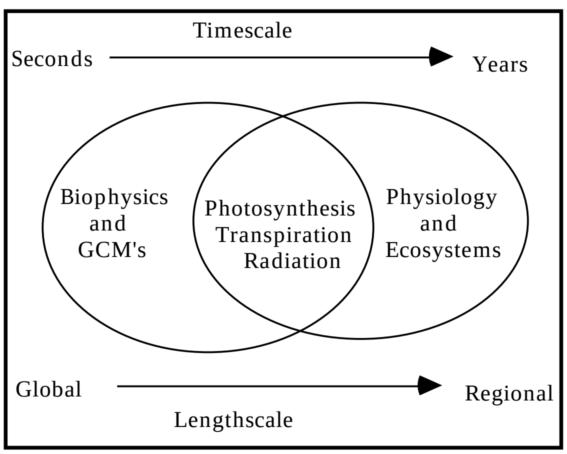

Figure 1. Relationship between biophysical and ecological components of the project.

One short-term focus of the work is to develop and use a coupled land-biosphere-atmosphere model to simulate the response of the physical climate system to both radiative and physiological changes induced by increasing CO_2. This model will have its surface boundary conditions largely specified from satellite data. Complementary work is focused on the develop- ment of a range of carbon cycle models operating over a wide range of time scales, which will be used to understand the follow-up response of the terrestrial biosphere to climate change.

Science Goal

The goal of the investigation is to first understand and then to predict the response of the coupled terrestrial biosphere-global atmosphere system to global change, specifically to the increase in atmospheric CO_2. In addition to improving our understanding of the critical components of the Earth system, this project should yield improved products of derived surface and atmospheric parameters, and will be directly useful in developing methodologies to extract the maximum benefit from EOS observations.

Current Activities

Within the *Biophysics and GCMs* area, the group has constructed a model (SiB2) of the land-atmosphere transfers of radiation, heat, water, and CO_2, which has been linked to the Colorado State University (CSU) GCM. The land surface vegetation conditions, including leaf area index, albedo, roughness length, and phenology, are all specified from analyses of a global satellite data set put together specifically for the project. The model is being used to examine global patterns of energy and carbon exchange and also to investigate the effects of increasing CO_2 on the biosphere and continental climates.

Parallel work makes use of the CSU GCM and other models in the tracer mode to understand the relationships between atmospheric CO_2 concentration fields and carbon sink/source dynamics.

On the *Physiology and Ecosystems* side, work has been focused on constructing a detailed carbon model (Carnegie-Ames-Stanford Approach [CASA]), which is being used to look at longer-term aspects of the carbon cycle. Related work is being done on improving remote-sensing tools to derive vegetation cover components and phenology.

Use of Satellite Data

The project will make strong use of the EOS AM and PM platform data. MODIS, MISR, and ASTER data will be used to define surface properties for the SiB2 and CASA models to replace those data sets that are currently derived from AVHRR observations. AIRS data will be used to check all aspects of the SiB2-GCM model performance including, among others, atmospheric states and radiation fields.

Participation in Field Programs

Many of the team members participate in field programs which aim to further our understanding of important processes as well as teach us how to better use satellite data in the models. These experiments have included:

- *FIFE*: A study of land-atmosphere exchanges and remote sensing. The experiment took place in Kansas in the late 1980's.
- *BOREAS*: Several investigators are taking part in this large-scale, interdisciplinary study of the functioning of the boreal forest. The study is taking place in Canada and embraces aspects of land-surface climatology, ecology, biogeochemistry, terrestrial ecology and remote sensing.
- *FIRE*: This is a study of atmospheric radiation transfer and the validation of remote sensing algorithms.

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Piers Sellers is an honors graduate of Edinburgh University, received a Ph.D. from Leeds University in 1981, and is currently based at NASA/Goddard Space Flight Center, Biospheric Sciences Branch. He has been extensively involved with the International Satellite Land Surface Climatology Project (ISLSCP), serving as Staff Scientist for the First ISLSCP Field Experiment (FIFE), and co-project scientist/manager of the Boreal Ecosystem-Atmosphere Study (BOREAS).

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Middle and High Latitude Oceanic Variability Study (MAHLOVS)

Principal Investigator—**Meric Srokosz**

Science Background

The aim of MAHLOVS is to investigate the variability of the atmospheric forcing of the oceans, the consequent effect on the oceanic response, and the resulting effect on the biological productivity of the oceans. Much effort is presently being expended on determining the long-term and large-scale means and trends in the structure of the oceans (for example, the WOCE and JGOFS programs). By the time of the launch of EOS, a good grasp of that problem should have been obtained. This study builds on that understanding by examining the spatial and temporal variability of the ocean (on space scales ranging from one-to-one-thousand kilometers and time scales of days to years), about these large-scale and long-term means and trends. This is likely to contribute to the U.K. component of CLIVAR (the successor to WOCE and TOGA). To understand changes in the atmosphere-ocean-biology system it is clear that knowledge about the variability of the system is necessary, as well as information about means and trends.

MAHLOVS concentrates on mid-to-high-latitude regions of the oceans, in particular the eastern North Atlantic and the Southern Ocean. These regions have been chosen because they are areas of significant atmosphere-ocean-biology interaction and variability and because there is a continuing U.K. oceanographic interest in them (they feature in the U.K. components of the WOCE and JGOFS programs). The latter consideration is important in that *in situ* data are therefore available for incorporation into this study. It is proposed to make use of the microwave, visible, and infrared sensors of the EOS system to calculate the sea surface forcing and fluxes, the dynamical variability of the ocean, and the biological activity. The data will be combined in a synergistic manner and assimilation of the data into ocean models (biological and physical) will be used to enhance the analysis, interpretation, and understanding of the phenomena observed.

Science Goal

The goal of this investigation is to examine the relationship between the temporal and spatial variability of the atmospheric forcing of the ocean and the consequent variability of the oceanic response and its effect on the biological productivity at mid-to-high latitudes (particularly in the eastern North Atlantic and the Southern Ocean). Specific scientific questions to be addressed are: 1) what changes occur over a ten-year period in the surface fluxes of momentum, heat, water, and radiation in the regions of interest, on space scales of the order of hundreds of kilometers and time scales of longer than one week; 2) what is the variability of the ocean circulation and biological activity in these areas and how do they relate to the variability of the surface forcing; 3) to what extent does the coupling of the eastern North Atlantic with the Norwegian Sea, the North Sea, and the Western Mediterranean affect its dynamical and biological variability; 4) in the Southern Ocean, what is the effect of the variability of the Antarctic Circumpolar Current on the biological activity; and 5) what are the differences and similarities between the eastern North Atlantic and the Southern Ocean?

Current Activities

Current studies include: 1) the relationship of remotely sensed sea surface data (particularly, altimetric height and infrared temperature) to sub-surface features; 2) the combination of radar altimeter and *in situ* measurements to monitor flow through the Drake

Passage; 3) the assimilation of ERS-1 altimeter data into an ocean model; 4) the development of biological and coupled biophysical models, and techniques for assimilation of data into such models; 5) relationships between the variability of the sea surface temperature, the sea surface topography, and wind forcing in the Atlantic Ocean; 6) examination of the effect of sampling on heat flux determination, leading to improved heat flux climatology; and 7) various technical studies to improve the calibration and quality of the remotely sensed data being used.

Use of Satellite Data

Prior to the launch of the EOS sensors, data from other satellite missions and sensors (Geosat, AVHRR, ERS-1 & 2, TOPEX/Poseidon, SeaWiFS, ADEOS) are being, or will be, used to carry out initial studies. Once EOS is launched, data from the radar altimeter, scatterometer (on ADEOS-II), MODIS, MIMR, AIRS/AMSU/MHS, and CERES will be used in combination to investigate atmosphere-ocean-biology interactions and variability. In addition, data from sensors on the NOAA polar orbiter series, the ESA ENVISAT and METOP missions, and the NASDA ADEOS-II mission will be used to complement those obtained from EOS. Important to the investigation is the requirement for simultaneity of observations from a number of sensors (the degree of simultaneity required depends on the particular process being studied), which will be available from EOS.

Participation in Field Programs

As well as requiring data from EOS, MAHLOVS uses *in situ* data acquired on research vessel cruises. These are from cruises planned specifically for MAHLOVS studies, and also from other U.K. cruise programs. In 1991 a cruise took place to tie-in with the launch of ERS-1 and data were acquired for the calibration and validation of the radar altimeter, the scatterometer, and the ATSR. In addition, studies were carried out to link remotely sensed sea surface data with the *in situ* sub-surface data. Another cruise is planned for 1996 after the launch of SeaWiFS, to study plankton patchiness using a combination of ship and satellite data. Data from various other cruises are also being used in MAHLOVS. Further cruises are planned to tie-in with the launch of the EOS platforms.

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Meric Srokosz has 16 years of experience in the fields of applied mathematics and remote sensing of the oceans. He holds both undergraduate and doctoral degrees in Mathematics from Bristol University. Currently, he is the head of the Remote Sensing Applications Development Unit (RSADU) of the U.K. Natural Environment Research Council (NERC), based at the Southampton Oceanography Centre (SOC)*. He is responsible for coordination of U.K. activities in remote sensing of the oceans, and for research into, and development of, applications of remote sensing to environmental science. Dr. Srokosz is a Principal Investigator for the ERS-1 and ERS-2 missions, and a Co-Investigator for the TOPEX/Poseidon and ADEOS missions.

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

Principal Investigator—**Byron D. Tapley**

Science Background

Momentum and mass transport between the atmosphere, oceans, and solid Earth produce changes in the Earth's rotation and its gravity field which are being measured by modern space geodetic techniques. Changes in rotation are attributable both to motions of winds in the atmosphere and currents in the oceans as well as to mass redistribution within the Earth system. Alternatively, changes in the gravity field, which can be inferred from satellite orbit perturbations, arise only from mass redistribution. Thus space geodetic measurements of Earth rotation, gravity variations, and satellite motions provide global measures of angular momentum and mass redistribution and can be used to study the mechanisms involved in these changes.

Details about the manner of mass and momentum exchange among the components of the Earth's dynamic system are not fully understood. The agents that transfer angular momentum between the atmosphere and the other components include torques from tangential surface frictional effects and from air pressure gradients across mountainous topography. Similarly, oceanic pressure differences across continental faces can also be important in transferring momentum from oceans to the solid Earth.

Earth rotation and gravity variations occur over many time scales and provide measures of such climate-related signals as seasonal fluctuations in atmospheric pressure and winds, the El Niño/Southern Oscillation interannual fluctuation, and longer term redistribution of water mass among ocean/continent/polar ice cap reservoirs. Appropriate global integrals of the mass and motion of air and water give predictions of gravity and rotation changes that can be compared with observations. These comparisons can be used to verify and improve models of the interaction of the oceans, atmosphere, and land surface hydrology. Energy redistribution across the ocean boundary is another process for which a quantitative assessment of atmosphere-ocean coupling interaction has not been fully achieved.

Science Goal

The objective of this investigation is to develop appropriate Earth system models for analyzing multisensor information from EOS satellites, along with *in situ* data and data from other satellites, to investigate the interactions of the atmosphere, oceans, and solid Earth, as represented by the exchange of angular momentum, mass, and energy among these components. A primary focus of the research will be to clarify the mechanisms that dynamically couple the atmosphere, oceans, and solid Earth. The study will also focus on understanding the relationship of changes in these quantities to global climate change processes. An important issue to be addressed is the impact of global warming on sea-level change.

Current Activities

The investigation is producing atmospheric angular momentum and related data sets derived from the wind and mass fields of the NASA Goddard Earth Observing System (GEOS) Data Assimilation System, as well as from operational analyses of the world's major weather centers. Variations in oceanic angular momentum due to mass redistribution and changes in currents are being studied as are interactions between the oceans and the Earth's solid crust. Output from ocean general circulation models using both barotropic and eddy-resolving realizations is being used to calculate and assess oceanic angular momentum and torque mechanisms. Monthly surface winds derived from scatterometry are being used to improve assessments of the global momentum budget beyond the result based on operational models.

In addition, research on ocean data assimilation using satellite altimeter, scatterometer, and radiometer data is being conducted to develop methodologies for ingesting these data into appropriate models for more-accurate computation of ocean circulations. Research on modeling of the terrestrial water cycle contributes to the understanding of the role of water mass storage in land processes.

In alternative studies, the TOPEX/Poseidon altimeter data are being used to measure the seasonal, interannual, and secular sea-level change. Analysis of two years of TOPEX/Poseidon sea-level data indicates that these measurements have the potential to determine the global variations of the mean sea level with an accuracy of 1 mm/yr.

Use of Satellite Data

The ocean and polar ice topography changes observed by the EOS radar and laser altimeter satellites, along with the Earth rotation and gravity field changes observed by satellite laser ranging, very-long-baseline interferometry, and GPS space geodesy techniques will be primary measurements for this investigation. The mass and momentum balances will require measurements from a number of EOS instruments. AIRS/AMSU/MHS will provide input for the temperature and moisture in the atmospheric momentum, mass, and water budgets. MIMR will be used to observe water vapor and provide information about surface winds over the ocean. SeaWinds will be used to provide measurements of sea surface wind vectors. EOS Radar ALT will provide sea surface topography, wind speed, and wave height measurements and measurements of global sea-level change. EOS Laser ALT will be used to provide changes in ice sheet elevations to provide a constraint on the global water budget. These two measurements will be crucial to measuring the impact of global warming on sea-level change.

In addition, other data sources, including many of the Pathfinder data sets, satellite radar altimetry data, and long-term space geodetic measurements, including the 20-year series of satellite laser ranging to geodetic satellites, will be utilized. The terrestrial reference frame determined by satellite laser ranging is an essential requirement for describing changes in the Earth system over multi-decadal time intervals.

Participation in Field Activities

Radar altimeter instrument calibration activities have been conducted, supporting the ESA ERS-1 Venice Tower calibration, and the NASA/CNES TOPEX/Poseidon Harvest Platform and Lampedusa calibrations. As part of the activities which support GLAS and accurate measurement of sea level, additional calibrations of TOPEX/Poseidon instruments are being conducted in the Galveston Bay region along the Texas coast. Team members provide atmospheric angular momentum data, as well as Earth rotation solutions, determined from geodetic satellites, to the International Earth Rotation Service.

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Byron Tapley earned a Ph.D. in Engineering Mechanics at The University of Texas at Austin, and has over 30 years of experience in the use of satellites for Earth observations. He has served on the National Research Council (NRC) Space Studies Board (SSB), the SSB Committee on Earth Studies, and the NRC Earth Studies Board Geodesy Committees. 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. He is also the Director of the Texas Space Grant Consortium. His research interests focus on the application of nonlinear parameter estimation methods to determine crustal motion, Earth rotation, the Earth's geopotential, and ocean circulation. He has served as Chairman of the Geodesy Section for the American Geophysical Union (AGU). He is the recipient of the NASA Exceptional Scientific Achievement Medal in 1983, the American Institute of Aeronautics and Astronautics (AIAA) Mechanics and Control of Flight Award in 1989, and the NASA Public Service Medal in 1995. He is member of the National Academy of Engineering and a Fellow of AGU, AIAA, and AAAS.

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

Principal Investigator—**Bruce A. Wielicki**

Science Background

The CERES-A interdisciplinary science (IDS) investigation will examine the role of clouds and radiative energy balance in the climate system. Studies include cloud feedback mechanisms which can greatly modify the response of the climate system to increased greenhouse gases. Initial CERES-A general circulation modeling (GCM) studies have shown that cloud-radiative heating might enhance the strength of the Hadley cell by as much as a factor of two.

As is typical in studies of global systems, a strategy must be determined to cover scientific problems at a wide range of time and space scales. We develop and apply a series of radiative and dynamical cloud models. The models range from highly detailed Large Eddy Simulation models which resolve scales between 50 meters and 5 km, to greatly simplified GCM cloud models which resolve scales between 200 km and global. Definitive progress is only made by a combination of careful observations and modeling studies made across all of the scales important for the understanding of cloud and radiation processes.

This IDS investigation is closely tied to the CERES instrument investigation. Our studies will be used to validate CERES instrument measurements and will use the CERES instrument data to study the role of clouds in the climate system. The CERES instrument investigation focuses on production of the cloud and radiation budget data needed for our investigation and other EOS-sponsored studies. These data products utilize not only CERES broadband radiance data, but also depend critically on cloud data derived using the VIRS (Visible and Infrared Scanner) on TRMM and using MODIS on EOS AM and EOS PM. The cloud properties are matched to each CERES broadband field of view, allowing derivation of a consistent set of cloud properties and radiative fluxes. The CERES instrument provides radiative flux estimates at the top of the atmosphere, at the surface, and at several levels within the atmosphere. These data are critical to the CERES-A climate system studies.

Science Goals

Goals of the investigation include: 1) extend the studies of cloud-radiative effects beyond the top of the atmosphere to the radiative balance at the surface of the Earth and to radiative heating/cooling within the atmosphere; 2) extend the studies of cloud-radiative effects using the more-accurate CERES top-of-atmosphere radiative fluxes; 3) examine the use of satellite-derived radiative fluxes to develop improvements in medium-range forecasting; and 4) validate the cloud properties and radiative fluxes produced by the CERES instrument investigation.

Current Activities

Studies are under way to examine the role of clouds in the tropical ocean heat balance, to examine the amount of atmospheric heating produced by the absorption of solar energy in clouds, and to examine potential cloud feedback systems. Recent studies have also included determination of the impact of the Pinatubo eruption on the Earth's radiative-energy balance.

Prospective validation of CERES instrument observations relies on direct observations of surface radiative fluxes (shortwave and longwave) as well as cloud properties using surface remote sensing (radiometers, lidar, and radar). Key surface data are being obtained, working jointly with the DOE ARM

(Atmospheric Radiation Measurement) program, the BSRN (Baseline Surface Radiation Network) of the World Climate Research Program, and phase III of the NASA FIRE (First ISCCP [International Satellite Cloud Climatology Project] Regional Cloud Experiment).

Use of Satellite Data

This interdisciplinary investigation will use the CERES *instrument* investigation data products as its prime source of global data on cloud properties and radiative fluxes. Other important input data for this investigation will include temperature and humidity profiles (NMC and EOS 4-D assimilation), sea surface and land temperatures (MODIS, AIRS), cloud liquid water (TMI, MIMR), and ocean surface winds (scatterometers). Other satellite data will also be examined to provide coverage of the global oceans and polar regions. For cloud properties, EOS satellite-based lidar (Laser ALT) as well as proposed future 3-mm cloud radar will be key to determining the effects of optically thin cirrus and overlapping cloud layers. For validation of the effects of non-plane-parallel clouds, the EOS MISR multi-angle radiance data will provide key tests of the accuracy of cloud-radiative models and remote sensing.

Participation in Field Programs

The CERES-A investigation is working closely with the FIRE-III cloud field experiment, which will be examining polar clouds and tropical cirrus in the next 5 years. CERES-A is also coordinating closely for a long time series of surface and in-atmosphere radiative flux measurements being taken as part of the DOE ARM program, the GEWEX (Global Energy and Water Cycle Experiment), and the WCRP BSRN surface measurement program.

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Bruce Wielicki was awarded a Ph.D. in Physical Oceanography from the Scripps Institution of Oceanography in 1980. He has focused primarily on atmospheric research concerning cloud properties, cloud remote sensing, and the Earth radiation budget. Following a 3-year assignment at NCAR, Dr. Wielicki joined NASA/Langley Research Center as a Research Scientist in 1980. While there he has served as a Principal Investigator on the Landsat Thematic Mapper science team, on the Earth Radiation Budget Experiment (ERBE) science team, and currently is a Principal Investigator for the First ISCCP Regional Experiment (FIRE). Dr. Wielicki received the NASA medal for Exceptional Scientific Achievement in 1992, and the American Meteorological Society Houghton Award in 1995.

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EOS Acronyms

AAOE	Airborne Antarctic Ozone Experiment
AATSR	Advanced Along-Track Scanning Radiometer
ACR	Active Cavity Radiometer
ACRIM	Active Cavity Radiometer Irradiance Monitor
ACRIMSAT	ACRIM Satellite
ADC	Affiliated Data Center
ADEOS	Advanced Earth Observing System
AES	Atmospheric Environment Service, *Canada*
AIRS	Atmospheric Infrared Sounder
ALOS	Advanced Land Observation Satellite
AMR	Tri-Frequency Altimetry Microwave Radiometer
AMSR	Advanced Microwave Scanning Radiometer
AMSU	Advanced Microwave Sounding Unit
AMTS	Advanced Meteorological Temperature Sounding Study
AO	Announcement of Opportunity
API	Application Programming Interface
APT	Automatic Picture Transmission
ARGOS	Argos Data Collection and Position Location System
ARM	Atmospheric Radiation Measurement Program
ASAR	Advanced Synthetic Aperture Radar
ASCAT	Advanced Scatterometer
ASF	Alaska SAR Facility
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATBD	Algorithm Theoretical Basis Document
ATLAS	Atmospheric Laboratory for Applications and Science
ATMOS	Atmospheric Observations Satellite
AVHRR	Advanced Very High-Resolution Radiometer
AVIRIS	Airborne Visible and Infrared Imaging Spectrometer
AVNIR	Advanced Visible and Near-Infrared Radiometer
BRDF	Bidirectional Reflectance Distribution Function
BSRN	Baseline Surface Radiation Network
CCD	Charge Coupled Device
CCRS	Canada Centre for Remote Sensing
CDDIS	Crustal Dynamics Data Information System
CDMS	Cryospheric Data Management System
CEES	Committee on Earth and Environmental Sciences
CENR	Committee on the Environment and Natural Resources Research
CEOS	Committee on Earth Observations Satellites
CERES	Clouds and the Earth's Radiant Energy System
CFC	Chlorofluorocarbon
CIESIN	Consortium for International Earth Science Information Network
CLAES	Cryogenic Limb Array Etalon Spectrometer
CNES	Centre National d'Etudes Spatiales
CNRS	Centre National de la Recherche Scientifique
COARE	Coupled Ocean-Atmosphere Response Experiment
CODMAC	Committee on Data Management, Archiving, and Computing
CPP	Cloud Photopolarimeter
CR	Correlation Radiometer
CRYSYS	Cryospheric System
CSA	Canadian Space Agency
CSIRO	Commonwealth Scientific and Industrial Research Organization
CSMS	Communications and System Management Segment
CZCS	Coastal Zone Color Scanner
DAAC	Distributed Active Archive Center
DADS	Data Archive and Distribution System
DAS	Direct Access System
DB	Direct Broadcast
DCS	Data Collection System
DDL	Direct Downlink
DFA	Dual-Frequency Radar Altimeter
DoC	Department of Commerce
DoD	Department of Defense
DoE	Department of Energy
DoI	Department of the Interior
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DoS	Department of State
DP	Direct Playback
DRSS	Data Relay Satellite System
DSB	Direct Sounding Broadcast
ECom	EOS Communications
ECS	EOSDIS Core System
EDC	EROS Data Center
EDOS	EOS Data and Operations System
EER	External Engineering Review
ELV	Expendable Launch Vehicle
ENSO	El Niño Southern Oscillation
ENVISAT	Environmental Satellite, *ESA*
EOC	EOS Operations Center
EO-ICWG	Earth Observations International Coordination Working Group
EOS	Earth Observing System
EOS AERO	EOS Aerosol Mission
EOS ALT	EOS Altimetry Mission
EOS AM	EOS Morning Crossing (Descending) Mission
EOS Color	EOS Color Mission
EOS CHEM	EOS Chemistry Mission
EOSDIS	EOS Data and Information System
EOSP	Earth Observing Scanning Polarimeter
EOS PM	EOS Afternoon Crossing (Ascending) Mission
EP	Earth Probe
EPA	Environmental Protection Agency

EPOP	European Polar-Orbiting Platform
ERBE	Earth Radiation Budget Experiment
ERBS	Earth Radiation Budget Satellite
EROS	Earth Resources Observation System
ERS	European Remote-Sensing Satellite
ERTS-1	Earth Resources Technology Satellite-1
ESA	European Space Agency
ESSC	Earth System Sciences Committee
ETM	Enhanced Thematic Mapper
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FCCSET	Federal Coordinating Council for Science, Engineering, and Technology
FIFE	First ISLSCP Field Experiment
FIRE	First ISCCP Regional Experiment
FOO	Flight of Opportunity
FOS	Flight Operations Segment
FOV	Field-of-View
FST	Field Support Terminal
GAC	Global Area Coverage
GCDIS	Global Change Data and Information System
GEO	Geostationary Earth Orbiter
Geosat	Navy Geodetic Satellite
GEWEX	Global Energy and Water Cycle Experiment
GFO	Geosat Follow-on
GGI	GPS Geoscience Instrument
GII	Geographic Information System
GISS	Goddard Institute for Space Studies
GLAS	Geoscience Laser Altimeter System
GLI	Global Imager
GLIS	Global Land Information System
GLRS	Geoscience Laser Ranging System
GMS	Geostationary Meteorological Satellite
GOES	Geostationary Operational Environmental Satellite
GOMI	Global Ozone Monitoring Instrument
GOMOS	Global Ozone Monitoring by Occultation of Stars
GOMR	Global Ozone Monitoring Radiometer
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
HDF	Hierarchical Data Format
HIRDLS	High-Resolution Dynamics Limb Sounder
HIRIS	High-Resolution Imaging Spectrometer
HIRS	High-Resolution Infrared Sounder
HIS	High-Resolution Interferometer Sounder
HRPT	High-Resolution Picture Transmission
IASI	Infrared Atmospheric Sounding Interferometer
ICC	Instrument Control Center
ICF	Instrument Control Facility
ICSU	International Council of Scientific Unions
IELV	Intermediate Expendable Launch Vehicle
IEOS	International Earth Observing System
IFOV	Instantaneous Field-of-View
IGBP	International Geosphere-Biosphere Program
ILAS	Improved Limb Atmospheric Spectrometer
IMG	Interferometric Monitor for Greenhouse Gases
IMS	Information Management System
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
IR	Infrared
IRTS	Infrared Temperature Sounder
ISAMS	Improved Stratospheric and Mesospheric Sounder
ISCCP	International Satellite Cloud Climatology Project
ISLSCP	International Satellite Land Surface Climatology Project
ISSA	International Space Station Alpha
IST	Instrument Support Terminal
ITIR	Intermediate Thermal Infrared Radiometer
IWG	Investigators Working Group
IWGDMGC	Interagency Working Group on Data Management for Global Change
JEOS	Japanese Earth Observing System
JERS	Japanese Earth Remote-Sensing Satellite
JGOFS	Joint Global Ocean Flux Study
JPOP	Japanese Polar-Orbiting Platform
LAC	Local Area Coverage
LAGEOS	Laser Geodynamics Satellite
Landsat	Land Remote-Sensing Satellite
LaRC	Langley Research Center
LATI	Landsat Advanced Technology Instrument
LERTS	Laboratoire d'Etudes et de Recherches en Teledetection Spatiale
LIMS	Limb Infrared Monitor of the Stratosphere
LIS	Lightning Imaging Sensor
LITE	Lidar In-Space Technology Experiment
LR	Laser Retroreflector
LRPT	Low-Resolution Picture Transmission
LTER	Long-Term Ecological Research
MELV	Medium Expendable Launch Vehicle
MERIS	Medium-Resolution Imaging Spectrometer
MESSR	Multispectrum Electronic Self-Scanning Radiometer
METEOR 3M-1	Russian Operational Weather Satellite
METOP	Meteorological Operational Satellite, *ESA, EUMETSAT, NOAA*
MHS	Microwave Humidity Sounder
MIMR	Multifrequency Imaging Microwave Radiometer
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MISR	Multi-Angle Imaging Spectroradiometer

MITI	Ministry of International Trade and Industry, *Japan*
MLELV	Medium-Light Expendable Launch Vehicle
MLS	Microwave Limb Sounder
MODIS	Moderate-Resolution Imaging Spectroradiometer
MOPITT	Measurements of Pollution in The Troposphere
MOS	Marine Observation Satellite
MOU	Memorandum of Understanding
MR	Microwave Radiometer
MSFC	Marshall Space Flight Center
MSR	Microwave Scanning Radiometer
MSS	Multispectral Scanner
MSU	Microwave Sounding Unit
MSX	Midcourse Space Experiment
MTI	Multispectral Thermal Imager
MTPE	Mission to Planet Earth
MTS	Microwave Temperature Sounder
NAS	National Academy of Sciences
NASDA	National Space Development Agency, *Japan*
NBIS	Northern Biosphere Information System
NCAR	National Center for Atmospheric Research
NCDS	NASA Climate Data System
NERC	National Environmental Research Centre
NESDIS	National Environmental Satellite, Data, and Information Service
NIST	National Institute of Standards and Technology
NMC	National Meteorological Center
NODS	NASA Ocean Data System
NPOESS	National Polar Orbiting Environmental Satellite System
NRA	NASA Research Announcement
NRC	National Research Council
NREN	National Research and Education Network
NSC	National Security Council
NSCAT	NASA Scatterometer
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center
NSN	NASA Space Network
NSpC	National Space Council
NSPD	National Space Policy Directive
NSTC	National Space and Technology Council
NWP	Numerical Weather Prediction
OCTS	Ocean Color and Temperature Scanner
ODB	Orbit Determination Beacon
ODUS	Ozone Dynamics Ultraviolet Spectrometer
OLS	Optical Line Scanner
OMB	Office of Management and Budget
OMTPE	Office of Mission to Planet Earth
ORNL	Oak Ridge National Laboratory
OSC	Orbital Sciences Corporation
OSTP	Office of Science and Technology Policy
PDQ	Panel on Data Quality
PGS	Product Generation System
PI	Principal Investigator
PLDS	Pilot Land Data System
PMR	Pressure-Modulated Radiometer
POD	Precision Orbit Determination
POEM	Polar-Orbit Earth Observation Mission
POES	Polar-Orbiting Operational Environmental Satellite
POLDER	Polarization and Directionality of Earth's Reflectances
POLES	Polar Exchange at the Sea Surface
PPR	Photopolarimeter Radiometer
PR	Precipitation Radar
PRAREE	Precise Range and Range Rate Equipment—Extended
RA	Radar Altimeter Instrument
Radarsat	Radar Satellite
RIS	Retroreflector In Space
S&R	Search and Rescue
SAA	Satellite Active Archive, *NOAA*
SAGE	Stratospheric Aerosol and Gas Experiment
SAMS	Stratospheric and Mesospheric Sounder
SAR	Synthetic Aperture Radar
SBUV	Solar Backscatter Ultraviolet
SCARAB	Scanner for the Radiation Budget
SCF	Science Computing Facility
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SDPS	Science Data Processing Segment
Seasat	Sea Satellite
SeaWiFS	Sea-Viewing Wide Field-of-View Sensor
SeaWinds	NASA Scatterometer for Flight on ADEOS II
SEDAC	Socio-Economic Data and Applications Center
SELV	Small Expendable Launch Vehicle
SEM	Space Environment Monitor
S-GCOS	Space-Based Global Change Observation System
SIR-C	Shuttle Imaging Radar-C
SLR	Satellite Laser Ranging
SMC	System Management Center
SMMR	Scanning Multispectral Microwave Radiometer
SOLSTICE	Solar Stellar Irradiance Comparison Experiment
SPOT	Systeme pour l'Observation de la Terre
SSBUV	Shuttle Solar Backscatter Ultraviolet
SSM/I	Special Sensor Microwave/Imager
SRL	Shuttle Research Laboratory
SSALT	Solid-State Altimeter
SSU	Stratospheric Sounding Unit
STA	Science and Technology Agency, Japan
STIKSCAT	Stick Scatterometer
SWAMP	Science Working Group for the AM Platform
SWG	Science Working Group

SWIR	Short Wavelength Infrared
TBD	To Be Determined
TDRSS	Tracking and Data Relay Satellite System
TES	Tropospheric Emission Spectrometer
TGDDIS	Trace Gas Dynamics Data Information System
TIR	Thermal Infrared
TIROS	Television and Infrared Observation Satellite
TM	Thematic Mapper
TMI	TRMM Microwave Imager
TMR	TOPEX Microwave Radiometer
TOGA	Tropical Ocean Global Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TOPEX/ Poseidon	Ocean Topography Experiment
TOVS	TIROS Operational Vertical Sounder
TPFO	TOPEX/Poseidon Follow-On
TRMM	Tropical Rainfall Measuring Mission
UARP	Upper Atmosphere Research Program
UARS	Upper Atmosphere Research Satellite
UAV	Unmanned Aerospace Vehicle
UHF	Ultra High Frequency
URL	Uniform Resource Locator
USDA	U.S. Department of Agriculture
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
USO	Ultra-Stable Oscillator
UV	Ultraviolet
V0	EOSDIS Version 0
VIRS	Visible Infrared Scanner
VIRSR	Visible Infrared Scanning Radiometer
VIS	Visible
VHF	Very High Frequency
VNIR	Visible and Near-Infrared
VSAR	Variable Synthetic Aperture Radar
VTIR	Visible and Thermal Infrared Radiometer
WCRP	World Climate Research Program
WFF	Wallops Flight Facility
WHOI	Woods Hole Oceanographic Institution
WOCE	World Ocean Circulation Experiment
WWW	World Wide Web
X-SAR	X-Band Synthetic Aperture Radar