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A JOINT REPORT

THE PAYLOAD ADVISORY PANEL
AND
THE DATA AND INFORMATION SYSTEM ADVISORY PANEL
OF
THE INVESTIGATORS WORKING GROUP OF THE

EARTH OBSERVING SYSTEM

DECEMBER 17, 1993

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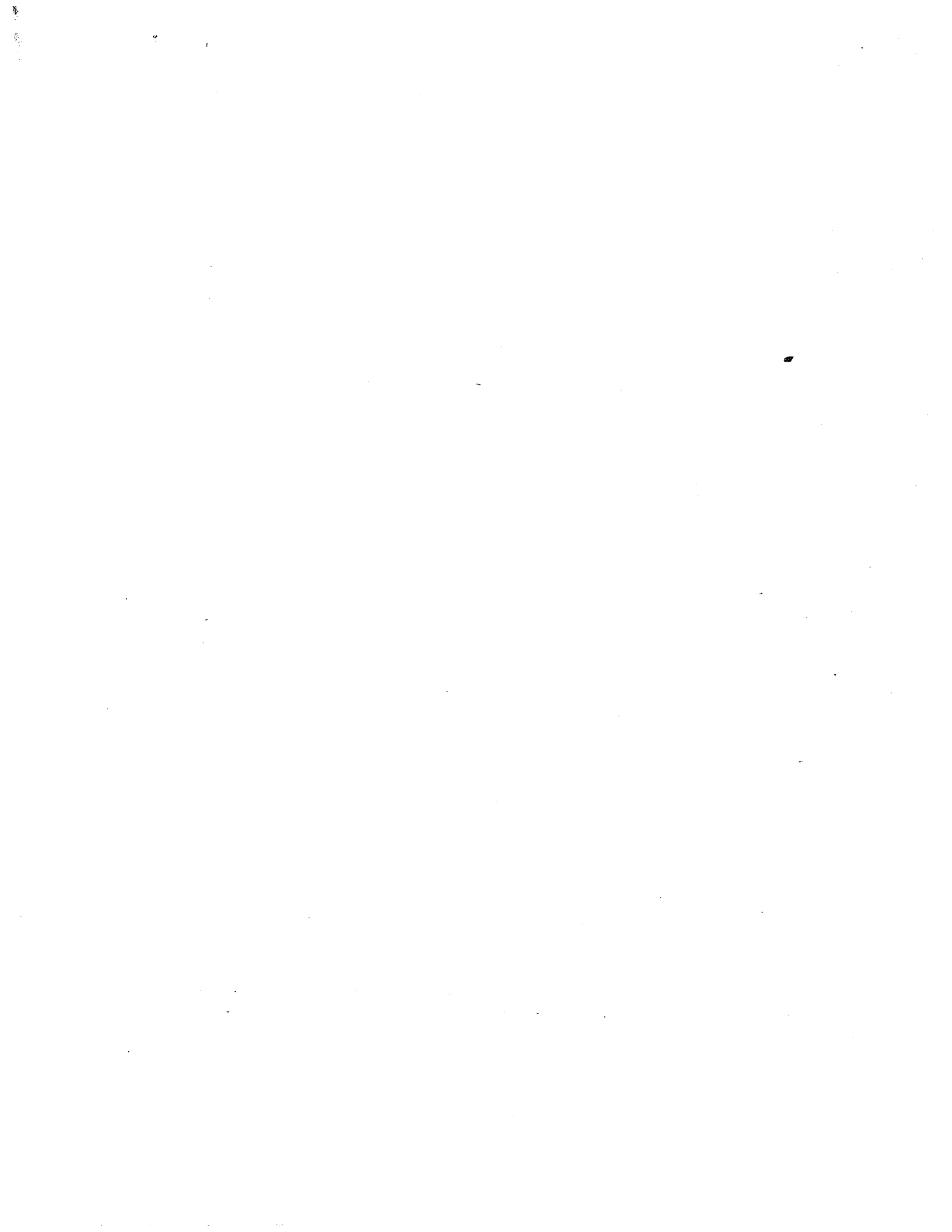
(NASA-TM-109847) THE PAYLOAD
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OF THE INVESTIGATORS WORKING GROUP
OF THE EARTH OBSERVING SYSTEM: A
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EXECUTIVE SUMMARY

A JOINT REPORT

THE PAYLOAD ADVISORY PANEL

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THE DATA AND INFORMATION SYSTEM ADVISORY PANEL

OF

THE INVESTIGATORS WORKING GROUP OF THE

EARTH OBSERVING SYSTEM

The Payload Advisory Panel of the Investigators Working Group (IWG) for the Earth Observing System (EOS) met 4 to 6 October 1993 in Herndon, Virginia. The Panel, originally composed of the Interdisciplinary Science Principal Investigators, was expanded to include all Principal Investigators and as such is now the IWG itself. The meeting also addressed directly a report from the EOSDIS (EOS Data and Information System) Advisory Panel.

The findings of the Herndon Meeting are being issued as a Joint Report of the Payload Advisory Panel and the EOSDIS Advisory Panel. The meeting focused on payload issues in the years 2000 to 2005; however, we considered some subjects in the nearer-term, most significantly EOSDIS. The overarching theme of convergence in Earth observations set a backdrop for the entire meeting.

I. CONVERGENCE IN EARTH REMOTE SENSING: IMPLICATIONS AND OPPORTUNITIES FOR THE EARTH OBSERVING SYSTEM

A. Overview

The *National Performance Review*, issued by Vice President Gore, has declared that the polar-orbiting Earth observation satellites of the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the Air Force's Defense Meteorological Satellite Program (DMSP) should converge into a less costly system. The EOS Payload Advisory Panel concurs that the convergence of systems offers opportunities for reductions in cost. The nation cannot afford ambitious, multiple parallel systems.

There are, however, dangers in "convergence" that would directly affect EOS and must be addressed.



- I.1. *To capture the benefits of a converged system while guarding against the dangers, the EOS Payload Advisory Panel recommends retention of parallel research and operations entities, housed in either one or several organizations. Parallel, coupled research and operations entities would ensure that new technologies and techniques transfer from research to operations and that the research arm is fully aware of the highest-leverage needs of operations.***
- I.2. *The Payload Advisory Panel recommends that the initial steps toward convergence begin with NOAA and DMSP satellites and their associated ground systems. The initial focus should be on joint management and operations. The consolidation should be under the civil entity.***

If the NOAA-DMSP convergence takes place, further mergers with NASA activities can be examined. As with the initial convergence, the merger should begin by creating a common management structure and satellite ground systems.

- I.3. *The Payload Advisory Panel does not now advise where such a converged system should locate in the federal government, other than stating that the consolidation should be within civil entity(ies). The institution(s) must fully support and be charged with the long-term, essentially permanent, observation of the Earth for research and applications. The converged system must accommodate the scientific needs for long-term, calibrated data, as well as an observational strategy that is flexible enough to address unforeseen issues in Global Change and to exploit advances in technologies.***

The timing of convergence greatly affects the realized cost savings. NOAA and DMSP have enough instruments and satellites currently in production to carry observations to about 2002-2004. The METOP-1 satellite of the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) will launch in late 2000 with a 5-year design lifetime in a polar orbit with a morning crossing and will carry NOAA operational instruments. The EOS PM-1 afternoon polar-orbiting spacecraft will launch in 2000, also with a 5-year design lifetime. The first spacecraft that convergence would affect are the NOAA and DMSP afternoon-orbiting satellites starting about 2002-2004. The next spacecraft would be the EOS AM-2, EOS PM-2 and METOP-2 in 2003-2005. Savings on management, operations, and data processing could begin somewhat sooner.

- I.4. *The Payload Advisory Panel will carefully reconsider the AM-2, PM-2, and Chem-2 payloads, considering convergence, the need for long-term measurements, and the growing recognition of the need for a robust, flexible observational strategy. This strategy must build on EOS AM-1, PM-1 and Chem-1, on NOAA TIROS,***



and on DMSP, and it must recognize explicitly the contributions and needs of our international partners.

B. EOS PM-1 Mission: A Stepping Stone to Convergence

The Payload Advisory Panel recognizes the central role that the EOS instruments have in convergence, especially the several EOS PM-1 instruments that are candidates for operational roles with either NOAA and/or EUMETSAT in the EOS PM-2 era. As a contribution to the convergence discussion, the Panel considered each of the EOS PM-1 platform instruments and their possible role in a converged system.

The Atmospheric Infrared Sounder (AIRS) will meet all scientific and operational requirements for an infrared sounding capability as defined by NASA and NOAA. NOAA has been involved from the outset in helping set the instrument requirements for spectral coverage and resolution, detector sensitivity, and data rates. Most importantly, in 1992 AIRS was descoped from a two-spectrometer design to a single spectrometer partly in response to NOAA requirements.

- I.5. The Payload Advisory Panel recommends that NASA, EOS, and the AIRS Project continue to involve NOAA in all aspects of the AIRS and to raise and resolve all specific issues and concerns as they arise. We strongly encourage the involvement of ESA, EUMETSAT and DoD. We reiterate our earlier recommendation that AIRS move to operational status about 2005.*

There is a danger that the Microwave Humidity Sounder (MHS) will not be available for the EOS PM-1 payload. This would be a serious blow to the science; moreover, the loss of MHS from EOS PM-1 would prevent NOAA from testing the full three-instrument suite, AIRS-AMSU-MHS, as a pre-operational system.

- I.6. The Payload Advisory Panel strongly recommends that NASA acquire an MHS (or AMSU-B) instrument for flight on the PM-1 platform.*

The science needs of NASA for passive microwave imagery can be met with an instrument that is currently being designed for both operational and scientific purposes by the European Space Agency (ESA). This instrument, the Multifrequency Imaging Microwave Radiometer (MIMR), follows the heritage of the Special Sensor Microwave Imager (SSM/I) on the DMSP spacecraft. A MIMR-class instrument is needed both for operational and research interests.

- I.7. The Payload Advisory Panel recommends that a joint NASA/NOAA/DoD study team work closely with ESA, EUMETSAT, and the MIMR Science Advisory Group and reflect any additional operational requirements that could contribute to*



improving the long-term utility of MIMR and passive microwave observing generally.

The Moderate Resolution Imaging Spectroradiometer (MODIS) provides key Global Change observations of cloud physical properties, aerosols, ocean color, ocean surface temperature, and land surface properties including vegetation, snow cover, and skin temperature. MODIS supplies data for many of the needs of the atmosphere, land, and ocean sciences.

I.8. The Payload Advisory Panel recommends that NASA work cooperatively with NOAA, DoD, and ESA/EUMETSAT to refine the requirements for a well-calibrated MODIS-class imaging radiometer that will simultaneously meet the needs of the Global Change and operational communities. This process will have to consider costs of the full system and accommodation issues as well as ESA's MERIS instrument.

Accurate measurements of radiative fluxes and of cloud properties are critical to solving problems connected with global climate change. The contribution of the Clouds and the Earth's Radiant Energy System (CERES) instrument to the retrieval of radiative fluxes is well documented, based on the experience of the Earth Radiation Budget Experiment (ERBE).

I.9. Because of the strong need for simultaneity between the cloud measurements and the radiative flux measurements, the Payload Advisory Panel recommends that MODIS, CERES, and MIMR instruments fly on the same platform.

The CERES instrument and software are being developed with full interaction with NOAA, who will have near real-time (within 2-3 hours) access to the CERES data for use in operational forecasts. Although NOAA has informally expressed an interest in obtaining CERES measurements for operational radiation budget fluxes and cloud forcing, DoD is unlikely to have a requirement for the CERES observations.

I.10. The Payload Advisory Panel recommends that NASA, EOS, and the CERES Project continue to involve NOAA, and where appropriate, ESA and EUMETSAT, in all aspects of the CERES instrument and software development and to raise and resolve all specific issues and concerns as they arise.

C. Convergence Summary

The EOS Payload Advisory Panel concludes that while convergence may provide long-term cost savings, a phased approach will best combine savings and system robustness. Efforts to merge management, spacecraft command and control, and data processing must precede convergence of spacecraft and instruments. A clear separation of operations and



R&D must be maintained, including some expansion capability in both operational and research spacecraft designs to allow for unexpected changes in requirements while maintaining the cost efficiency of purchases of multiple units. Finally, any converged system must meet the requirement for highly calibrated, long-term, continuous measurements for EOS satellite observations in support of the US Global Change Research Program (USGCRP).

II. ATMOSPHERIC CHEMISTRY: EOS CHEM AND EOS AERO

A. EOS Chem-1 Mission

The Payload Advisory Panel is convinced that the EOS Chem-1 Mission will provide a comprehensive series of measurements that address key science questions in three critical areas: climate change, ozone depletion, and the changing chemistry of the troposphere. The Payload Advisory Panel believes, however, that a few important changes in the EOS Chem-1 Mission can significantly and cost-effectively improve the scientific return.

II.1. The Payload Advisory Panel recommends that ACRIM fly before EOS Chem-1 to avoid data gaps that will reduce the scientific value of the ACRIM data set. The Panel requests that NASA aggressively explore the possibility of refitting the ACRIM ATLAS instrument for early flight (1996-1998) on a longer-duration spacecraft. Possibilities include a small spacecraft, the NOAA TIROS Series, and either EOS AM-1 or PM-1.

We note that ACRIM need not fly on any particular EOS platform, including EOS Chem-1. ACRIM simply needs to fly on a series of spacecraft that will allow the development of a long-term, continuous record of solar variability.

The EOS Chem-1 payload measures the set of atmospheric chemistry and aerosol variables identified by the EOS Atmospheres Panel as essential to monitor the chemical, aerosol, and radiative processes that control ozone.

II.2. The Payload Advisory Panel continues to endorse the measurement of OH as provided by the enhanced MLS. OH is a key radical controlling ozone loss in the lower stratosphere and is a critical component in the monitoring strategy of EOS Chem-1.

II.3. The Payload Advisory Panel endorses the UARS-equivalent SOLSTICE II instrument for long-term accurate UV flux measurements. Regrettably, in the constrained budget environment, the Panel is unable to recommend the SURE option. This enhancement would improve greatly our understanding of the Sun-Earth connection, but its particular contribution to clarifying issues of Global Change is less central. We note that flight of SOLSTICE II on the EOS Chem-1 Platform is not essential for any other instrument; therefore,



SOLSTICE II could fly on another spacecraft in the 2002–2004 time-frame if another option proves more affordable.

II.4. The Payload Advisory Panel endorses the New TOMS instrument that NASDA will provide as the CII (Chemistry International Instrument) contribution to the EOS Chem-1 Payload. New TOMS will continue the long-term, high quality column ozone measurements made by the NASA TOMS instruments before the launch of EOS Chem-1.

The Payload Advisory Panel recognizes that scientific issues associated with tropospheric chemistry are high on the list of national and international priorities. The Mission to Planet Earth can respond better to those priorities by moving TES forward from AM-2 to Chem-1. Similar lower stratospheric and upper tropospheric data from HIRDLS, MLS and SAGE III provide a strong synergism because all four instruments will measure key trace gases at altitudes from 10 to 25 km. The combined data enhance science and allow for important intercomparisons among instruments. In addition, the New TOMS will also provide important information on the changing chemistry of the troposphere. When combined with HIRDLS, MLS or SAGE III data, New TOMS data can be used to derive tropospheric ozone, increasing the synergism with TES on the EOS Chem-1 Platform

II.5. The Payload Panel strongly recommends moving TES from EOS AM-2 to EOS Chem-1.

B. EOS Aero Mission and SAGE III

SAGE III, in a mid-inclination orbit, along with SAGE III on EOS Chem-1, yields the required global coverage for its long-term, self-calibrating measurements.

II.6. The Payload Advisory Panel reiterates its recommendation for an early flight of SAGE III in a mid-inclination orbit (56°-73°) to continue the measurements by the SAGE series. The Panel notes with concern that NASA has neither identified nor budgeted a spacecraft for Aero, the mid-inclination mission, in the EOS program.

C. Relation to ENVISAT I and II

The Payload Advisory Panel accepted a launch of EOS Chem-1 Mission after the year 2000 because of fiscal constraints and because of the recognition that ESA's ENVISAT I Mission could provide key measurements of important chemical species in the atmosphere throughout 1998-2002.

II.7. The EOS Payload Advisory Panel strongly supports our European colleagues in implementing the technically challenging and scientifically important ENVISAT I Mission.



ENVISAT is a crucially important international component in the effort to understand global environmental change. Understanding and coping with this issue clearly exceeds the capabilities of any one nation; it is a global problem and will require global responses.

II.8. The Payload Advisory Panel will continue seeking to foster the necessary cooperation and coordination between NASA and its domestic and international partners. The Payload Advisory Panel extends its appreciation for the spirit of cooperation and good will shown by all of our international partners.

III. REMOTE SENSING OF THE GLOBAL CYCLES OF ENERGY, WATER, AND CARBON IN EOS

The EOS AM-1 payload will provide us with a vastly improved observation and understanding of the global cycles of energy, water and carbon, particularly over the continents. The AM-1 Mission will provide surface boundary conditions for calculating the surface-atmosphere fluxes of energy, water, and carbon on short (seconds to interannual) time-scales.

Recently, some progress has been made in our understanding of the global carbon cycle. This progress and its implications will be reflected in the upcoming 1994 Assessment of the Intergovernmental Panel on Climate Change (IPCC).

A. The Carbon Cycle: Implications for Land Remote Sensing

Human-induced changes to the global carbon cycle are one of the most significant drivers of Global Change. Future concentrations of atmospheric CO₂, the proximate forcing for climate and vegetation changes, are a function of sources such as fossil fuel burning and deforestation and of sinks in the oceans and land vegetation and soils. There are three terms in the terrestrial carbon budget that must be considered, each requiring a somewhat different remote sensing strategy.

1. First are the annual, nearly balanced, fluxes of CO₂ into the biosphere (photosynthesis) and into the atmosphere (plant and soil respiration), with some interannual variability caused by the *El Niño* Southern Oscillation (ENSO), major droughts, and other climate anomalies. EOS scientists have articulated a clear strategy for estimating global photosynthesis, relying primarily on MODIS and MISR to capture seasonal and interannual variability in the large scale dynamics of vegetation.
2. Second, land use changes, particularly deforestation in the tropics, cause a release of CO₂ to the atmosphere. Satellite measurements of forest clearing rates are a first-order requirement for quantifying the carbon fluxes associated with land clearing. The work by the Brazilian National Space Agency (INPE) has shown significant interannual variability in rates of deforestation. To measure such variations, we need coverage annually or at least every other year. The EOS Landsat Pathfinder activity



has shown that Landsat-5 spatial and spectral resolutions are ideal for large-scale mapping of vegetation changes.

III.1. The Payload Advisory Panel states strongly that the programmatic structure for Landsat must provide data for Global Change priorities. Convergence of systems must not obstruct acquisition of these important data. This is ever more urgent with the failure of Landsat 6 to reach orbit and the fragile condition of Landsats 4 and 5.

III.2. The Payload Advisory Panel and EOSDIS Advisory Panel jointly recommend a thorough independent review of the estimated cost of the data system for Landsat 7, including data processing for the Enhanced Thematic Mapper (ETM) and High-Resolution Multispectral Instrument (HRMSI).

3. Third is the problem of the "missing sink." The missing sink is commonly assumed to be linked to the increase in atmospheric CO₂, although changes in the age structure of forests caused by intense mid-latitude harvesting in the late 1900s and atmospheric deposition of nitrogen also play a role. The issue is central to the determination of the atmospheric lifetime of CO₂; the questions are open and important.

A promising avenue for measuring these changes in ecosystem physiology is through the remote sensing of canopy chemistry. The only proposed approach to measuring canopy chemistry on adequate spatial scales is through spectrometry at high spectral resolution. The recent empirical studies of the Accelerated Canopy Chemistry Program (ACCP) provide encouraging empirical and some theoretical evidence that space-borne spectrometers will provide considerable information on canopy chemistry.

III.3. The Payload Advisory Panel recommends that funding for the HIRIS team, at least that portion central to the current focus of canopy chemistry, be continued through the successful conclusion of the HIRIS Team's Accelerated Canopy Chemistry Program (ACCP).

III.4. The Payload Advisory Panel further recommends that the final report of the HIRIS Team's ACCP be carefully peer reviewed. If the Report and the review are positive about the potential, scientific utility of this technology, then NASA might develop a relatively modest, space-borne mission for the 1999–2002 period to advance the technological and scientific base. To accommodate this possibility, the planning for this mission should begin now.



This experimental, low cost mission should be part of the Earth Probes program and use a small launch vehicle and low orbit; the latter would allow a significant savings through the use of smaller optics.

B. Remote Sensing of the Land in the EOS Era: EOS AM-2, EOS PM-2, and Landsat 7/8

If TES is moved from the AM-2 platform to Chem-1, then we should carefully consider placement of a land-surface imaging system on the AM-2 platform that would strongly complement the simultaneous viewing with MODIS and MISR. The requirements of this land-observing instrument suite need to be defined in the context of the discussions for the Advanced Land Remote Sensing System (ALRSS), the results anticipated from ASTER and SPOT, which do not adequately address the required coverage, and the ACCP efforts in the use of hyper-spectral imagery.

III.5. The Payload Advisory Panel recommends a careful reconsideration of the high-resolution land remote sensing strategy for the EOS AM-2 era and beyond. This strategy must consider not only the scientific demands and potential payloads but also the issues of convergence and the contribution of international partners.

We are especially concerned with current arrangements for "reconciling" the needs of the Global Change research community and of the defense community in the design and operation of the ALRSS. We are also particularly concerned about the high cost of the Landsat program, particularly Landsat 7 and its data system. See also Recommendations III.1 and III.2.

IV. OCEAN AND LAND-ICE ALTIMETRY: EOS ALT

The science objectives of EOS Land-Ice Altimetry and EOS Ocean Altimetry dictate that these sensors be on separate spacecraft.

IV.1. The Payload Advisory Panel recommends that the Project proceed with plans for separate EOS spacecraft missions for land-ice altimetry and ocean altimetry.

A. Ocean Altimetry

The global sea surface topography currently being measured by the TOPEX/Poseidon Mission is of unparalleled accuracy and is 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.



IV.2. The Payload Advisory Panel recommends that the EOS Program and Project explore options for ensuring that the important measurements provided by the current TOPEX/Poseidon mission be continued to bridge the gap between the end of TOPEX/Poseidon and the launch of EOS Ocean Alt.

Two options are feasible:

1. *The TOPEX/Poseidon Follow-On (TPFO).* This mission, to be conducted jointly with Centre National d'Etudes Spatiales (CNES) and NOAA for a launch in 1998, is the preferred option because it would be compatible with actual TOPEX measurement performance. This option must, however, face a significant budget hurdle. It would require a New Start and a budget commitment in 1995. This budget commitment would be external and in addition to the current EOS program.
2. *The GEOSAT Follow-On (GFO).* This Mission is currently being developed by the United States Navy for launch in 1996. For this to be a viable "Gap Filler" several changes would be necessary in order to meet the EOS Science Objectives:
 - a. add dual frequency altimeter to correct for ionosphere;
 - b. transmit full wave form data;
 - c. boost sampling rate of altimeter to reduce noise;
 - d. add laser retro-reflector cubes for ground tracking and calibration and validation;
 - e. release all tracking data to the civilian community, and
 - f. keep the international TOPEX/Poseidon Science and Data Processing team in place.

In addition, it would be preferable if the orbit were consistent with TOPEX/Poseidon.

IV.3. The Payload Advisory Panel recommends that NASA vigorously explore the GFO option, because of the difficult budget environment. However, the TPFO option is the most desirable bridge to the EOS Ocean Alt.

B. Land and Ice Altimetry

1. *Land-Ice Altimetry.* The Geoscience Laser Altimeter System (GLAS) is the essential instrument for polar ice sheets, whose mass balances affect predictions of global sea level change, a key IPCC issue of scientific uncertainty.

IV.4. The Payload Advisory Panel recommends that strategies be explored for advancing the launch date of the GLAS instrument.

2. *GPS Geoscience Instrument.* In view of the continuing problems with GPS signal restriction (anti-spoofing), and the importance of the GPS to EOS Alt missions,



IV.5. The Payload Advisory Panel recommends that the GPS Geoscience Instrument (GGI) team focus on developing the codeless receiver technology.

3. ***Tracking and Data Relay Satellite System.*** The use of Tracking And Data Relay Satellite System (TDRSS) has a significant negative impact on the cost and design of small spacecraft. This could directly impact the EOS Alt Missions.

IV.6. The Payload Advisory Panel recommends that NASA assess the relative advantages and disadvantages of TDRSS, particularly for the smaller EOS platforms, before enforcing a hard TDRSS requirement. The assessment must consider the full system, including both the space and ground segments.

V. THE EOS DATA AND INFORMATION SYSTEM

A. The State Of The System

The three-year blackout surrounding the procurement of the EOSDIS Core System (ECS) contractor has ended, and in March 1993 NASA selected Hughes Applied Information Systems (HAIS) as the primary contractor. In the interval, EOS itself has changed substantially, hence the requirements of the information system have changed. The EOS IWG and its EOSDIS Advisory Panel had their first views of the revised requirements, architecture, and design of EOSDIS in September 1993.

We have high hopes for a system that will provide us with easy, affordable, and reliable access to EOS information and other appropriate Earth science data in a modern computing environment throughout the next two decades. However, we now see a danger that the system may not have essential attributes we had envisioned. There are fundamental flaws in the current architecture and design and in the plans for implementation. The Project and Contractor are now working on a new architecture.

The currently proposed system must have strong connectivity to the user community and embrace a problem-solving approach to EOSDIS development. It must avoid becoming mired in details of fulfilling "requirements" without a high-level vision of the fundamental attributes of a successful data system. The Project, Contractor, and the proposed information system must show adequate adaptability to function in a user-driven, evolutionary environment. If EOSDIS is to be successful, then its architecture, design, and implementation require substantial changes, which are now in progress.

B. Recommendations

V.1. The EOS Payload Advisory Panel and the EOSDIS Advisory Panel strongly recommend that NASA work with the user community to fix EOSDIS. Furthermore, it must respond to comments from the National Research Council's Panel to Review EOSDIS Plans.



- V.2. *More specifically, the EOS Payload Advisory Panel and the EOSDIS Advisory Panel recommend the following actions, in priority order:***
- a. *Rewrite the Requirements Specification.***
 - b. *Embark on studies of alternative architecture.***
 - c. *Strengthen the awareness of users' needs within the Project and Contractor.***
 - d. *Create a logical distribution of EOSDIS.***
 - e. *Fund a vigorous and independent prototyping program.***
 - f. *Focus on the needs of the science community.***
 - g. *Identify key people and assign responsibilities.***
 - h. *Become more aware of non-governmental data systems.***
 - i. *Increase coordination with other NASA projects.***

C. Closure

For the next few months, we need to be patient and give the Project and the Contractor a chance to begin to solve these problems. We need to have confidence that they can respond.

We must not wait indefinitely. NASA must fix EOSDIS soon. If we do not see substantial improvement by January 1994, if we do not have confidence that EOSDIS is on the road to recovery by then, we must take more significant steps.

We proposed an informal system review—revised requirements, cost breakdown, architecture, design, and plans for maintenance and operations—before the next meeting of the EOS IWG, January 11-13, 1994. The system review was conducted December 13-14, 1993 with members of the EOSDIS Advisory Panel and a larger group of representatives from NASA HQ, EOSDIS Project, the Contractor, and the information science community. From the evidence presented at this review, the EOSDIS Advisory Panel is evaluating the leadership of the EOSDIS Project and Contractor and their commitment to evolution, distribution, creativity, excellence, and economical operation. Our initial reaction is positive.

- V.3. *At the January 1994 IWG meeting, the IWG will hear a report from its EOSDIS Advisory Panel and make recommendations to NASA about directions for EOSDIS.***



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The Payload Advisory Panel of the Investigators Working Group (IWG) for the Earth Observing System (EOS) met 4–6 October 1993 in Herndon, Virginia, USA. The Panel, originally composed of the Interdisciplinary Science Principal Investigators, was expanded to include all Principal Investigators and as such is the IWG, itself (Appendix I). The meeting also addressed directly a report of the EOS Data and Information System (EOSDIS) Advisory Panel. Several international partners and colleagues from the National Oceanic and Atmospheric Administration joined us. Appendix II lists the participants and the agenda.

The findings of the Herndon Meeting are being issued as a Joint Report of the Payload Advisory Panel and the EOSDIS Advisory Panel. The meeting focused on issues in the 2000–2005 time-frame; however, we considered some nearer-term issues. The overarching theme of convergence in Earth observations set a backdrop for the entire meeting.

I. CONVERGENCE IN EARTH REMOTE SENSING: IMPLICATIONS AND OPPORTUNITIES FOR THE EARTH OBSERVING SYSTEM (EOS)

A. OVERVIEW

The *National Performance Review*, issued by Vice President Gore, has declared that the polar-orbiting Earth observation satellites of the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the Air Force's Defense Meteorological Satellite Program (DMSP) should converge into a less costly system. The EOS Payload Advisory Panel concurs that the convergence of systems offers opportunities for reductions in management overhead, satellite control facilities, data processing and distribution systems, and—notably for the NOAA and DMSP systems—reductions in the number of required satellites and launches.

There are, however, at least two dangers in “convergence” that would directly affect EOS and, therefore, should be addressed before too many steps are taken along the path to convergence in Earth remote sensing. First, in spite of the high national priorities for both operations and research, there is a potential for operations to dominate and crowd out advanced research. Operational requirements being operational must, in a sense, win in a battle of priorities with research. Consequently, in order to insure the existence of research missions and functions, there must be a degree of autonomy and independence.

A second danger is that any reduction in the next-generation research and development missions can lead to a downstream loss in operational capabilities, and since operational capabilities are derived from previous research activities, there can be a downstream loss in operational advances. This out-year loss may not be sufficiently recognized if convergence is an overly cost-driven enterprise as opposed to following a performance-driven rationale. In any converged system, a vigorous research and development (R&D) program must be sustained to develop new observational concepts and technologies and to secure the transfer of those found to be successful and cost-effective to operational use.



- I.1. To capture the benefits of a converged system while guarding against the dangers, the EOS Payload Advisory Panel recommends retention of parallel research and operations entities, housed in either one or several organizations. Parallel, coupled research and operations entities would ensure that new technologies and techniques transfer from research to operations and that the research arm is fully aware of the highest-leverage needs of operations.***

Convergence nationally should begin with the operational agencies (e.g., NOAA and DoD), focus initially on management and operations, and then move to converged satellites.

The Panel recognizes the importance of the evolving international, convergence agreements between the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) and NOAA. Currently, these agreements commit NOAA to provide the afternoon polar orbit, while EUMETSAT provides the launch and spacecraft to fly NOAA operational instruments, as well as their own instruments, in the morning polar orbit on their METOP-1 Mission (~ 2000). These agreements will result in a significant cost savings to the U.S. government and must be accommodated in any convergence plans.

In a converged DMSP-NOAA satellite system, a reduction from a four US spacecraft system to a two US and one European spacecraft system may be an appropriate long-term goal. One scenario for meeting this goal would be an early AM DMSP-like mission, EUMETSAT's METOP series for the mid-AM crossing, and the NOAA afternoon TIROS spacecraft with some accommodation for DMSP instruments. A complication, however, is the reluctance of DoD operations to depend on any foreign data sources.

The Payload Advisory Panel recognizes that there are a host of difficult issues that must be resolved and that progress must be made evolutionary rather than revolutionary. Too much is at risk for chaos to rule.

- I.2. The Payload Advisory Panel recommends that the initial steps toward convergence begin with NOAA and DMSP satellites and their associated ground systems. The initial focus should be on joint management and operations. The consolidation should be under the civil entity.***

If the NOAA-DMSP convergence takes place, further mergers with NASA activities can be examined. As with the initial convergence, the merger should begin by creating a common management structure and satellite ground systems. Satellite instruments and the spacecraft themselves must be examined on a case-by-case basis to ensure that decisions are based on the best engineering and scientific principles.

- I.3. The Payload Advisory Panel does not now advise where such a converged system should locate in the federal government, other than stating that the consolidation should be within civil***



entity(ies). The institution(s) must fully support and be charged with the long-term, essentially permanent, observation of the Earth for research and applications. The converged system must accommodate the scientific needs for long-term, calibrated data, as well as an observational strategy that is flexible enough to address unforeseen issues in Global Change and to exploit advances in technologies.

Finally, the timing of convergence greatly impacts the realized cost savings. NOAA and DMSP have sufficient instruments and satellites currently in production to carry observations to about 2002-2004. The EUMETSAT METOP-1 satellite will launch in late 2000 with a 5 year design lifetime in the morning polar orbit carrying NOAA operational instruments. The EOS PM-1 afternoon polar orbiting spacecraft will launch in 2000, also with a 5 year design lifetime. The first spacecraft to be affected by convergence would be the NOAA afternoon orbit and DMSP orbits starting about 2002-2004. The next spacecraft would be the EOS AM-2, EOS PM-2 and METOP-2 in 2003-2005 time-frame. Given a 5-6 year process for phase A/B, phase C/D, and actual instrument and spacecraft construction, cost savings on instruments and spacecraft might occur beginning in 1997. Savings on management, operations, and data processing could begin somewhat sooner.

Some of the savings generated by a convergence should be used to improve the operational system. There are two major types of improvements which need additional funding. First, NOAA and defense needs would profit immensely from moving proven capabilities for ocean scatterometry and TOPEX-class altimetry to a full operational status. Second, additional resources are required to demonstrate new technologies such as laser wind sounding, synthetic aperture radar, and hyper-spectral imaging. Both of these needed improvements have been blocked by insufficient budgets.

1.4. The Payload Advisory Panel will carefully reconsider the AM-2, PM-2, and Chem-2 payloads, considering convergence, the need for long-term measurements, and the growing recognition of the need for a robust, flexible observational strategy. This strategy must build on EOS AM-1, PM-1 and Chem-1, on NOAA TIROS, and on DMSP, and it must recognize explicitly the contributions and needs of our international partners.

B. EOS PM-1 MISSION: A STEPPING STONE TO CONVERGENCE

The Payload Advisory Panel recognizes the important role that the EOS instruments have in the convergence context. This role is central for the EOS PM-1 instruments since several are candidate instruments for operational roles with either NOAA and/or EUMETSAT in the EOS PM-2 era. As a contribution to the convergence discussion, the Panel considered each of the EOS PM-1 platform instruments and their possible role in a converged system. Where appropriate, we compared these instruments to their DMSP and NOAA counterparts, considering their appropriateness for scientific use in climate monitoring and in physical process studies of the Earth system. We also examined the history of cooperation in operational and research use of each PM instrument. These



considerations lead to recommendations which we believe are responsive to and appropriate for the current and evolving situation. Subsequent examinations will require a careful assessment of reproduction cost of instruments, cost to accommodate the instrument on other spacecraft, and the cost to process the data, including consideration of the relation to EOS Data and Information System (EOSDIS).

Temperature and Water Vapor Sounding: Convergence

In 1988 NASA considered a spectrometer, the Atmospheric Infrared Sounder (AIRS), and an interferometer for flight on EOS. Following a comprehensive system evaluation, AIRS was selected over the interferometer to meet the scientific and programmatic requirements of both NASA research and NOAA operations. On the research side, AIRS advances the investigation of several basic questions regarding Global Change that have been outlined by the Intergovernmental Panel on Climate Change (IPCC) and the United States Global Change Research Program (USGCRP). On the operations side and in recognition that there is significant overlap between operations and research, NOAA has been involved from the outset in helping set the instrument requirements for spectral coverage and resolution, detector sensitivity, and data rates. A NOAA-NASA-DoD team set the requirements for accuracy of the derived temperature profile as 1° K in 1 km thick layers in the troposphere. NOAA representatives have been involved in all subsequent instrument reviews both at JPL and the contractor Loral and have made significant contributions to the evolving design of the instrument. In 1992 AIRS was descoped from a two-spectrometer design to a single spectrometer partly in response to NOAA requirements. The resulting descoped design in now is phase C/D.

AIRS will still meet all scientific requirements for an infrared sounding capability as defined by NASA and NOAA. The development issues associated with AIRS will be resolved in advance of the time when NOAA (and DoD) will be required to produce new operational instruments for flight on a converged satellite system. The current design of AIRS is estimated to have a 95% probability of providing a five-year life. Flight of the first AIRS on the PM-1 platform will provide proof of concept and allow development of processing algorithms to proceed in advance of the operational mission.

Operational flight of AIRS in a combined EOS/NOAA program will provide significant cost savings, meeting the stated intent of the Administration and Congress. The President of Loral/LIRIS has guaranteed NOAA that AIRS would be made available for operational use at \$18M per unit, exclusive of integration and GSS costs.

- 1.5. The Payload Advisory Panel recommends that NASA, EOS, and the AIRS Project continue to involve NOAA in all aspect of the AIRS and to raise and resolve all specific issues and concerns as they arise. We strongly encourage the involvement of the ESA, EUMETSAT, and DoD. We reiterate our earlier recommendation that AIRS move to operational status in the 2005 period.***



Humidity sounding: Convergence

Accurate humidity profiles are crucial parameters for the study of the energy and hydrologic cycle as well as climate modeling and weather prediction. The contribution of a Microwave Humidity Sounder (MHS) to the retrieval of accurate humidity profiles, including full overcast conditions, has been well established by the AIRS/AMSU/MHS Team. The sounding system of AIRS/AMSU/MHS will be able to retrieve humidity (and temperature) profiles under all cloud and weather conditions.

Furthermore, the sounding system on the PM platform is designed to function as a true prototype operational system for NOAA. Although NOAA and NASA can depend on AIRS/AMSU to improve the retrieval capabilities of water vapor, allowing high quality humidity measurements under most conditions, it will still depend on MHS to provide added sensitivity under overcast conditions. NOAA would likely regard the loss of MHS on the EOS PM-1 as loss of a vital pre-operational demonstration of improved capabilities originally developed by NOAA with "AMSU B". The software algorithm currently planned by NOAA integrates data from AIRS/AMSU/MHS as a prototype operational algorithm. The loss of MHS will prevent NOAA from testing the full three instrument suite as a pre-operational system, and costly modification of the software package would be required.

1.6. The Payload Advisory Panel strongly recommends that NASA acquire an MHS (or AMSU-B) instrument for flight on the PM-1 platform.

We recognize the difficulty of budget constraints, and the Panel will work closely with the EOS project to explore all options to obtain an MHS-class instrument at low cost.

Passive Microwave Imaging: Convergence

The science needs of NASA for passive microwave imagery can be met with instrumentation that is currently being designed for both operational and scientific purposes by the European Space Agency (ESA). This instrument, the Multifrequency Imaging Microwave Radiometer (MIMR), follows the heritage of the Special Sensor Microwave Imager (SSM/I) on the DMSP spacecraft. A MIMR-class instrument is needed both for operational and research interests. The design utilizes "external" calibration, as do current operational instruments (SSM/I, MSU, SSM/T and SSM/T2). Calibration is highly desirable for operations, and it is a necessity for Global Change research.

The selection of channels for retrieving various geophysical parameters is also uniform across both operational and scientific interests. These include frequencies at or near:

- a. 6 and 10.7 GHz for sea surface temperatures (SST), heavy oceanic rainfall, oceanic surface wind speeds, snow cover, and soil moisture;
- b. 19 GHz for moderate oceanic rainfall and cloud water, sea ice, snow cover, and vegetation parameters;
- c. 22 GHz for oceanic water vapor;
- d. 37 GHz for oceanic cloud water, sea ice, snow cover, and vegetation, and



- e. 90 GHz for rainfall over land, identification of deep convection, and land surface temperature.

To meet both science and operational needs these frequencies should include dual linear (H and V) polarization in a conically scanning instrument with the maximum swath width compatible with a reasonable Earth incidence angle and spatial resolution. The 6 GHz channel drives the spatial resolution requirement, and thus the size of the instrument, with 50 km spatial resolution being preferable and 100 km being useful.

The most likely area of diverging requirements for NOAA/NASA/DoD convergence is the DMSP need for maximum swath width, which the 705 km EOS PM-1 orbit might not satisfy. Other instrument parameters can probably be more easily resolved, such as specific frequency selection, antenna size and performance, scan rate, and view angle. Also, the possible desirability of adding temperature sounding channels needs to be addressed because the DMSP program already includes the SSM/T channels in the current development of the SSM/IS.

In summary, the Panel expects that an externally calibrated, conically scanning microwave imager with a range of dual polarized frequencies from 6 to 90 GHz would satisfy the full range of both operational and scientific interests.

- 1.7. The Payload Advisory Panel recommends that a joint NASA/NOAA/DoD study team work closely with ESA, EUMETSAT, and the MIMR Science Advisory Group and reflect any additional operational requirements that could contribute to improving the long-term utility of MIMR and passive microwave observing generally.*

Land, Ocean, and Atmosphere Imager: Convergence

The Moderate Resolution Imaging Spectroradiometer (MODIS) provides key Global Change observations of cloud physical properties, aerosols, ocean color, ocean SST, and land surface properties including vegetation and skin temperature. MODIS is in fact a convergence of many of the needs of the atmosphere, land, and ocean sciences.

For Global Change monitoring, MODIS will provide a new standard for well-calibrated, stable imaging radiometers, especially for the solar reflectance channels used for cloud properties, ocean phytoplankton, and land vegetation measurements. The on-board calibration and the enhanced spatial and spectral resolution of MODIS, relative to AVHRR/3 or OLS instruments, provide the capability to advance from classically qualitative measurements provided by past operational imagers to quantitative cloud, atmosphere, ocean, and land properties. In particular, the AVHRR/3 and OLS spectral information is far too limited to discriminate quantitatively many of the critical types of ocean phytoplankton, land vegetation, and clouds needed for Global Change studies.

For monitoring and process studies associated with the role of clouds and radiation, the rapid time and space variability of cloud radiative properties require that MODIS cloud property observations and CERES broad band radiation observations be conducted from the same spacecraft or from two spacecraft sampling the same volume of air within about



2-5 minutes. The same time simultaneity with a MIMR class observation of cloud liquid water path is highly desirable, but simultaneity within 15-30 minutes would be acceptable.

While MODIS would meet all of NOAA's current requirements, it is larger, more difficult to accommodate, and more costly than an AVHRR/3 class instrument. In addition, the Air Force requires that all image pixels in a scan line have the same size field of view on the ground with a pixel size no larger than 1 km. The constant field of view simplifies real-time use of the data in the field. A constant field-of-view modification to MODIS may be costly, but NASA should consider on-board processing of the data to spatially average the MODIS 250 meter nadir resolution visible band data to 1 km across the entire scan. Provision of a visible channel for night-time observations under lunar illumination might also be a useful modification of the MODIS design.

It is not obvious, without a careful cost analysis, whether multiple copies of a modified MODIS design would be less expensive than unmodified copies of MODIS in addition to copies of a merged DoD /NOAA/EUMETSAT imager.

- 1.8. *The Payload Advisory Panel recommends that NASA work cooperatively with NOAA, DoD, and ESA/EUMETSAT to refine the requirements for a well-calibrated MODIS-class imaging radiometer that will simultaneously meet the needs of the Global Change and operational communities. This process will have to consider full system costs and accommodation issues as well as ESA's MERIS instrument.*

Radiation Budget: Convergence

Accurate measurements of radiative fluxes and of cloud properties are critical parts of the problems connected with global climate change. The contribution of the Clouds and the Earth's Radiant Energy System (CERES) instrument to the retrieval of radiative fluxes is well documented, based on the experience of the Earth Radiation Budget Experiment (ERBE). We now know that a broad-band, scanning radiometer system, with multiple platforms, can establish the radiation balance of the planet, as well as the effects of clouds on the current climate system. In this sense, the measurement of top-of-the-atmosphere radiative fluxes can contribute to our understanding of the climate system.

However, prediction of the impact of global warming needs more than just the top-of-atmosphere fluxes that have been ERBE's legacy. At this point, the modeling community needs consistent measurements of cloud properties and radiative fluxes and not separate measurements. Indeed, one of the critical aspects of this problem is that if the cloud property measurements are separated in time from the radiative flux measurements by more than about 2 minutes, cause and effect relationships for clouds and radiation will be seriously corrupted by sampling noise, and it is unlikely that we will be able to build satisfactorily the required consistency into the data products.

Scientifically, the need for simultaneity is stronger for the synergism between clouds and radiation budget than for other types of atmospheric or surface parameters. Both temperature and perhaps atmospheric humidity appear to have relatively stable spatial and



temporal structure, so that measurements of these parameters that are separated by 30 minutes or less from the radiation fluxes are likely to be satisfactory. The same applies to stratospheric constituents and aerosols. It would be very helpful, however, to have measurements of liquid or solid water from microwave sensors on the same satellite to ensure simultaneity between condensed cloud water and the radiative fluxes.

1.9. Because of the strong need for simultaneity between the cloud measurements and the radiative flux measurements, the Payload Advisory Panel recommends that MODIS, CERES, and MIMR instruments fly on the same platform.

The CERES instrument and software are being developed with full interaction with NOAA. NOAA personnel have been involved in the CERES instrument development and are actively participating in the CERES software development. NOAA will have near real-time (within 2-3 hours) access to the CERES data for use in operational forecasts.

Although NOAA has informally expressed an interest in obtaining CERES measurements for operational radiation budget fluxes and cloud forcing, DoD is unlikely to have a requirement for the CERES observations.

1.10. The Payload Advisory Panel recommends that NASA, EOS, and the CERES Project continue to involve NOAA, and where appropriate, ESA and EUMETSAT, in all aspects of the CERES instrument and software development and to raise and resolve all specific issues and concerns as they arise.

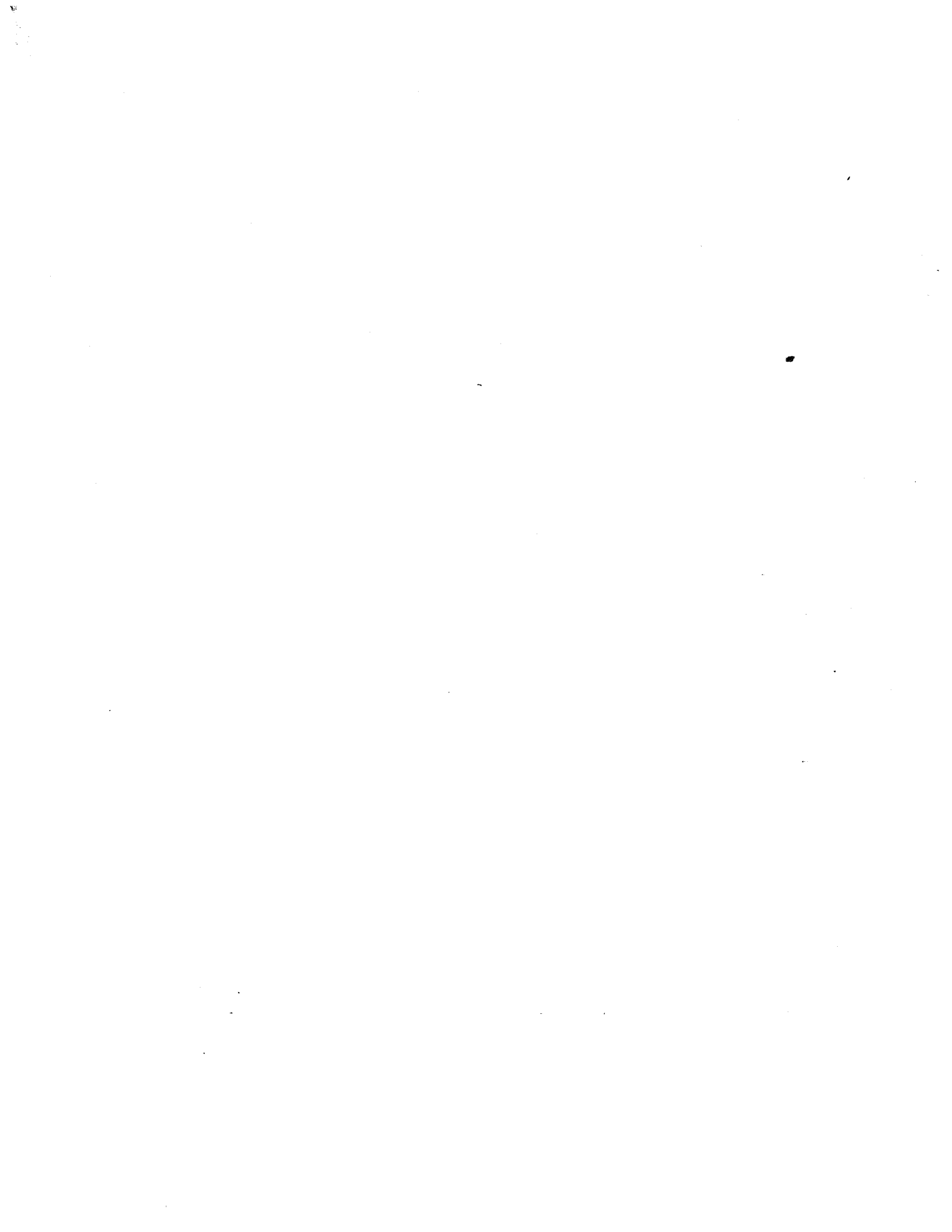
C. CONVERGENCE SUMMARY

The EOS Payload Advisory Panel concludes that while convergence may provide long-term cost savings, a phased approach will best combine savings and system robustness. Efforts to merge management, spacecraft command and control, and data processing must precede convergence of spacecraft and instruments. A clear separation of operations and R&D must be maintained, including some expansion capability in both operational and research spacecraft designs in order to allow for unexpected requirements changes while maintaining the cost efficiency of multiple unit purchases. Finally, any converged system must be capable of meeting the highly calibrated, long-term and continuous, measurement requirements for EOS satellite observations in support of the U.S. Global Change Research Program (USGCRP).

II. ATMOSPHERIC CHEMISTRY: EOS CHEM AND EOS AERO

A. EOS CHEM MISSION

The Payload Advisory Panel strongly endorses the EOS Chem-1 payload, which currently consists of HIRDLS, MLS, SAGE III, ACRIM, SOLSTICE II, and the Chemistry International Instrument (CII). This payload will provide a comprehensive series of measurements that address key science questions in three critical areas: climate change,



ozone depletion, and the changing chemistry of the troposphere. The Payload Advisory Panel believes, however, that the scientific return can be measurably improved in a cost effective manner by making a small number of important changes in the EOS Chem-1 Mission.

Climate Change

The EOS Chem-1 payload makes measurements of lower stratospheric and upper tropospheric ozone, water vapor, aerosols and other radiatively-active trace species whose measurements are needed to understand forcing and feedback processes associated with climate change. These measurements directly address important issues identified by the IPCC.

1. HIRDLS, MLS, and SAGE III provide water vapor and ozone measurements in the tropopause region. MLS will make these measurements in the presence of clouds. HIRDLS will make high horizontal resolution measurements of these and other radiatively-active constituents, while SAGE III will make high vertical resolution measurements.
2. SAGE III will provide aerosol distribution and characterization in the middle stratosphere to the middle troposphere.
3. ACRIM provides a continuation of solar constant measurements made by similar instruments on Solar Maximum Mission (SMM), Nimbus 7 and Upper Atmosphere Research Satellite (UARS). SOLSTICE II will provide a continuation of the solar ultraviolet (UV) flux measurements made on UARS.

The long-term accuracy of ACRIM measurements requires overlapping satellite data records to assess the effects of solar variability on climate (Appendix III). Short ACRIM flights (e.g., shuttle ATLAS flights) do not provide required knowledge of solar variability compared to longer duration flights.

II.1. The Payload Advisory Panel recommends that ACRIM fly before EOS Chem-1 to avoid data gaps that will reduce the scientific value of the ACRIM data set. The Panel requests that NASA aggressively explore the possibility of refitting the ACRIM ATLAS instrument for early flight (1996-1998) on a longer-duration spacecraft. Possibilities include a small spacecraft, the NOAA TIROS Series, and either EOS AM-1 or PM-1.

We note that ACRIM need not fly on any particular EOS Polar Platform, including EOS Chem-1. ACRIM simply needs to fly on a series of spacecraft that would allow the development of a long-term, continuous record of solar variability; this record could be maintained with 15 minutes observing time on each orbit or even once a day is likely to be sufficient.

Ozone Depletion

The EOS Chem-1 payload makes the set of atmospheric chemistry and aerosol measurements identified by the EOS Atmospheres Panel as essential to monitor the



chemical, aerosol, and radiative processes that control ozone. These measurements will be made during the period of peak, anthropogenic chlorine loading of the stratosphere. The Panel is convinced that these measurements are critical for the assessment of ozone depletion processes.

II. The Payload Advisory Panel continues to endorse the measurement of OH as provided by the enhanced MLS. OH is a key radical controlling ozone loss in the lower stratosphere and is a critical component in the monitoring strategy of EOS Chem-1.

II.3. The Payload Advisory Panel endorses the UARS-equivalent SOLSTICE II instrument for long-term accurate UV flux measurements. Regrettably, in the constrained budget environment, the Panel is unable to recommend the SURE option. This enhancement would improve greatly our understanding of the Sun-Earth connection, but its particular contribution to clarifying issues of Global Change is less central. We note that flight of SOLSTICE II on the EOS Chem-1 Platform is not essential for any other instrument; therefore, SOLSTICE II could fly on another spacecraft in the 2002-2004 time-frame if another option proves more affordable.

II.4. The Payload Advisory Panel endorses the New TOMS instrument that NASDA will provide as the CII (Chemistry International Instrument) contribution to the EOS Chem-1 Payload. New TOMS will continue the long-term, high quality column ozone measurements made by the NASA TOMS instruments before the launch of EOS Chem-1.

Tropospheric Chemistry

The Payload Advisory Panel recognizes that scientific issues associated with tropospheric chemistry are high on the list of national and international priorities.

1. The Mission to Planet Earth can be more responsive to those priorities by moving TES forward from AM-2 to Chem-1. This accomplishes two things. First, similar lower stratospheric and upper tropospheric measurements by HIRDLS, MLS and SAGE III provide a strong synergism. All four instruments will make measurements of key trace gases in the 10-25 km range. This allows for important instrument intercomparisons and scientific enhancement. Second, TES chemical measurements will be available a full year earlier.
2. The New TOMS will also provide important information on the changing chemistry of the troposphere. When combined with HIRDLS, MLS or SAGE III data, New TOMS data can be used to derive tropospheric ozone. This further increases the synergism with TES on the EOS Chem-1 Platform.



II.5. The Payload Panel strongly recommends moving TES from EOS AM-2 to EOS Chem-1.

B. EOS AERO MISSION / SAGE III

SAGE III, in a mid-inclination orbit, along with SAGE III on EOS Chem-1 yields the required global coverage for its long-term, self-calibrating measurements.

II.6. The Payload Advisory Panel reiterates its recommendation for an early flight of SAGE III in a mid-inclination orbit (56°-73°) to continue the measurements by the SAGE series. The Panel notes with concern that NASA has neither identified nor budgeted a spacecraft for Aero, the mid-inclination mission, in the EOS program.

C. RELATION TO ENVISAT-1 AND -2

The Payload Advisory Panel accepted a launch of EOS Chem-1 Mission after the year 2000 because of fiscal constraints and because of the recognition that the European Space Agency's ENVISAT-1 Mission could provide an important number of key measurements of important chemical species in the atmosphere throughout the 1998–2002 time-frame.

II.7. The EOS Payload Advisory Panel strongly supports our European colleagues in implementing the technically challenging and scientifically important ENVISAT-1 Mission.

We hope that ENVISAT-2 measurements will be selected to complement the EOS Chem-1 payload and add robustness to the suite of atmospheric chemistry measurements needed to assess Global Change.

ENVISAT is but one of several crucially important international components in the effort to understand global environmental change. Understanding and coping with this issue clearly exceeds the capabilities of any one nation; it is a global problem and will require global responses.

II.8. The Payload Advisory Panel will continue seeking to foster the necessary cooperation and coordination between NASA and its domestic and international partners. The Payload Advisory Panel extends its appreciation for the spirit of cooperation and good will shown by all of our international partners.

III. REMOTE SENSING OF THE GLOBAL CYCLES OF ENERGY, WATER, AND CARBON IN EOS

The EOS AM-1 payload will provide us with a vastly improved capability for observing and understanding the global cycles of energy, water and carbon, particularly over the continents. In brief, EOS AM-1 data should yield precise information on the biophysical functioning of the terrestrial and oceanic biota and strong inferences on associated



biogeochemical processes. The data will be used to provide time-varying fields of photosynthetic properties, surface conductance to water vapor transfer, and albedo over the land. Over the oceans, the AM-1 mission will allow the determination of photosynthetic properties and sea surface temperatures. In short, the AM-1 Mission will provide the surface boundary conditions for calculating with models the surface-atmosphere fluxes of energy, water, and carbon on short (seconds to interannual) time-scales.

The science methods and requirements for this general area have been covered in some detail in other EOS documents. Recently, some progress has been made in our understanding of the global carbon cycle. This progress and its implications will be reflected in the upcoming Intergovernmental Panel on Climate Change (IPCC) 1994 Assessment and consequently warrant additional discussion in our Report.

A. THE CARBON CYCLE: IMPLICATIONS FOR LAND REMOTE SENSING

Human-induced changes to the global carbon cycle are one of the most significant drivers of Global Change. Future concentrations of atmospheric CO₂, the proximate forcing for climate and vegetation changes, are a function of sources such as fossil fuel burning and deforestation and of sinks in the oceans and land vegetation and soils. There are three terms in the terrestrial carbon budget that must be considered, each requiring a somewhat different remote sensing strategy.

1. First are the annual, nearly balanced, fluxes of CO₂ into the biosphere (photosynthesis) and into the atmosphere (plant and soil respiration). These fluxes are normally assumed to be of order 100 Pg C-CO₂ per annum each, with some interannual variability due to *El Niño* Southern Oscillation (ENSO) events, major droughts, and other climate anomalies. A clear strategy for estimating global photosynthesis has been articulated within EOS relying primarily on MODIS and MISR to capture seasonal and interannual variability in the large scale dynamics of vegetation. The MODIS instrument is crucial for estimating the gross biospheric exchange fluxes, their seasonal and interannual variability, and their coupling to the hydrological cycle. Because estimation of these fluxes requires specification of photosynthetic efficiency (kg/MJ intercepted radiation), the quality of these estimates will ultimately be improved by remote sensing of spatial and seasonal variations in canopy physiology, discussed in paragraph 3.
2. Second, land use changes, particularly deforestation in the tropics, cause a release of CO₂ to the atmosphere. Satellite measurements of forest clearing rates are a first-order requirement for quantifying the carbon fluxes associated with land clearing. Recent work has shown that spatial resolution of 30 m is required, because of the scale and spatial patterns of forest clearing. Use of kilometer-scale resolution data by themselves results in significant overestimates of clearing rates. In addition, the work by the Brazilian National Space Agency (INPE) has shown significant interannual variability in rates of deforestation. In order to measure such variations, annual coverage or at least every other year is required. Further, the EOS Landsat Pathfinder activity has shown that Landsat spectral resolution is sufficient to distinguish between primary forest, agricultural land (including

pastures) and secondary forest. Understanding the role of deforestation in the global carbon cycle will require continuity of Landsat-type measurements with approximately 30 m resolution and an observing strategy that will allow comprehensive coverage of the tropics on an annual basis. Seasonal studies are, for the most part, not necessary for this application. Additional spatial or spectral resolution are not required for this important issue.

III.1. The Payload Advisory Panel states strongly that the programmatic structure for Landsat must provide data for Global Change priorities. Convergence of systems must not obstruct acquisition of these important data. This is ever more urgent with the failure of Landsat 6 to reach orbit and the fragile condition of Landsats 4 and 5.

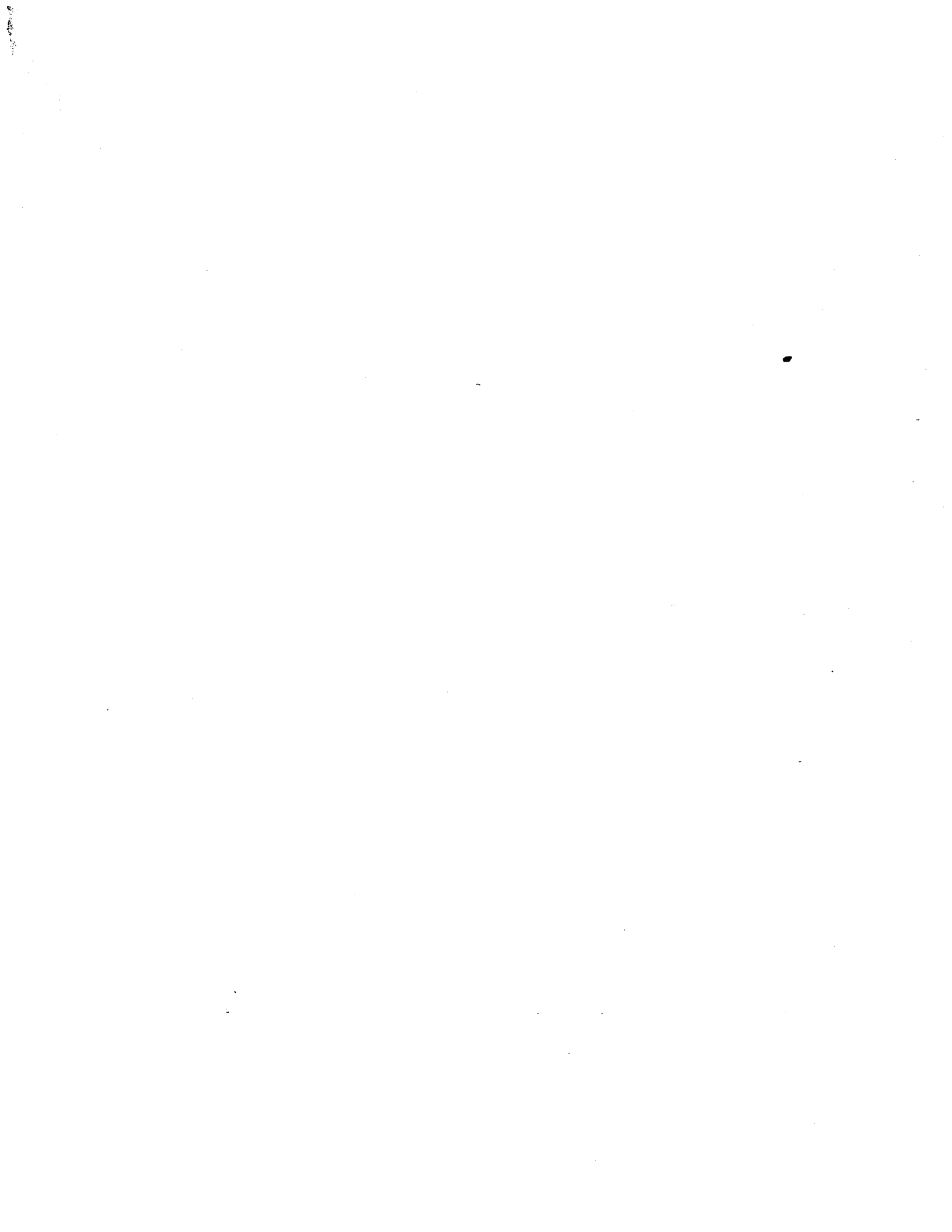
III.2. The Payload Advisory Panel and EOSDIS Advisory Panel jointly recommend a thorough independent review of the estimated cost of the data system for Landsat 7, including data processing for the Enhanced Thematic Mapper (ETM) and High-Resolution Multispectral Instrument (HRMSI).

3. Third is the problem of the 'missing sink'. The atmospheric carbon budget, in simplified terms, consists of the following terms, shown as annual averages for the decade of the 1980s:

<i>Sources (Pg C/yr)</i>		<i>Sinks (Pg C/yr)</i>	
Fossil fuels	5.4	Atmospheric increase	3.2
Deforestation	1.6	Ocean uptake	2.0
		'Missing sink'	1.8

Recent satellite-based studies of deforestation have, in general, reduced estimates of the deforestation flux. This has helped to reduce the estimate of the missing sink, which is calculated as difference between the directly measured or modeled sources and sinks. Improved global satellite estimates of deforestation thus serve to refine the estimation of the missing term, and thus bound the magnitude of the processes resulting in the additional unaccounted-for uptake.

The missing sink is commonly assumed to be linked to the increase in atmospheric CO₂, although changes in the age structure of forests due to intense mid-latitude harvesting in the late 1900s and atmospheric deposition of N are also thought to play a role. When the size of the missing sink is fit empirically to atmospheric CO₂ ('the beta factor') and extrapolated into the future, this results in a substantially altered prediction for the growth rate of atmospheric CO₂ relative to simulations without this feedback. Unfortunately, independent evidence for direct CO₂ fertilization of the biosphere remains contradictory. Both experimental and modeling studies have produced contradictory results. The issue is central to the determination of the atmospheric lifetime of CO₂; the questions are open and important.



In addition to the uncertainty regarding the current situation, it is likely that future changes in the activity of the biosphere will be reflected in the chemical composition of plant canopies. The effects of climate, CO₂ and atmospheric nitrogen deposition should all produce responses in canopy chemistry. A promising avenue for the remote sensing these changes in ecosystem physiology is through the remote sensing of canopy chemistry. The effects of canopy chemistry are not only on photosynthesis but also on decomposition, because the chemical composition of foliage affects its subsequent decomposition. Canopy chemistry is thus the only land surface quantity that provides direct information on rates of heterotrophic (respiratory) processes. In addition to monitoring change, remote observations of canopy physiology could improve MODIS-based studies of the spatial variability or the gross biospheric exchange fluxes by providing additional correlates of photosynthetic efficiency, leaf nitrogen concentration and chlorophyll density.

The only proposed approach to measuring canopy chemistry on adequate spatial scales is through the use of high spectral resolution spectroscopy.

The recent empirical studies of the HIRIS team and collaborators provide encouraging empirical and some theoretical evidence that space-borne spectrometers will provide considerable information on canopy chemistry (Appendix IV). After HIRIS's deselection, this is an area not covered by any current or proposed EOS experiments or observations.

III.3. The Payload Advisory Panel recommends that funding for the HIRIS team, at least that portion central to the current focus of canopy chemistry, be continued through the successful conclusion of the HIRIS Team's Accelerated Canopy Chemistry Program (ACCP).

III.4. The Payload Advisory Panel further recommends that the final report of the HIRIS Team's ACCP be carefully peer reviewed. If the Report and the review are positive about the potential, scientific utility of this technology, then NASA might develop a relatively modest, space-borne mission for the 1999-2002 period to advance the technological and scientific base. To accommodate this possibility, the planning for this mission should begin now.

This experimental, low cost mission should be designed for the Earth Probes program; therefore it must use a small launch vehicle and low orbit to allow a significant savings by using smaller optics. The developmental mission would also permit use of more advanced technology.

If the scientific data from this experimental mission indicate that a more ambitious approach is justified and if the resources are available, then a hyperspectral instrument could still be considered for the EOS AM-2 payload.



B. REMOTE SENSING OF THE LAND IN THE EOS ERA: EOS AM-2, EOS PM-2, AND LANDSAT 7/8

Measurements and science products from MODIS, MISR, and ASTER on EOS-AM-1 will have provided four years' observations of surface properties that govern the surface-atmosphere exchange of energy, water, and aspects of carbon flux. Specifically, over the land, time-varying fields of FPAR, leaf area index, photosynthetic capacity, albedo, and other biophysical properties should permit the calculation of continuous field of gross primary production (GPP), evaporation and net radiation, using sophisticated data products driven partly by satellite instrument data streams from AM-1 and PM-1 (e.g., AIRS/AMSU/MHS, CERES, and MIMR) as well as from the geostationary meteorological platforms. Given what we know from the work with AVHRR data, it is certain that these fields will exhibit large seasonal and interannual changes. These variations, combined with global tracer data and inverse calculations, should help provide insights into the carbon cycle. These insights, combined with the contributions coming from progress in canopy chemistry (hyperspectral imagery) and the constraints imposed by observed land-use patterns (e.g., from Landsat, SPOT, and ASTER), should provide for a new understanding of the terrestrial carbon cycle as well as a better grasp of the role of terrestrial systems in determining global climate.

Over the oceans, MODIS, MISR, CERES, and EOS Color data will be similarly employed to calculate fields of ocean chlorophyll, SSTs, and incident radiation. These data can be combined with ocean circulation models to contribute again to the calculation of energy, water, and carbon fluxes. Ocean topography (e.g., TOPEX/Poseidon) and oceanic winds from scatterometers (e.g., ADEOS-2, ERS-1, and ERS-2) will be invaluable. This again is evidence of the essential international nature of Mission to Planet Earth.

From the perspective of biophysics in Global Change and remote sensing, what must continue on EOS AM-2? The core instrument cluster for remote sensing the surface boundary layer conditions governing the flux of energy-water-carbon cycles must be kept in place. While much will be learned from EOS AM-1, maintenance of a continuous, high quality record is essential for the needed understanding and documentation of changes in climate and carbon flux. We assume that AM-2 will operate in the context of an effective meteorological satellite program.

We are concerned, however, about the ability to continue to characterize adequately the land surface, particularly land use and land cover. It is and will continue to be critical to maintain the now substantial record built up by Landsat-class instruments with their demonstrably valuable compromise between spatial resolution, spectral coverage, swath width, and repeat coverage.

Continuation of a Landsat-type measurement (wall-to-wall coverage, about 200 km swath, with ~30m resolution and spectral requirements sufficient to allow classification work and separation of green vegetation from woody material and soils) through the EOS era is crucial.

If TES moves forward from the AM-2 platform to the Chem-1 mission, then NASA should carefully consider placement of a land surface imaging system on the AM-2 platform that would strongly complement the simultaneous viewing with MODIS and



MISR. The requirements of this land observing instrument suite need to be defined in the context of the Landsat discussions, the results anticipated from ASTER and SPOT (which do not adequately address the required coverage), and the ACCP efforts in the use of hyperspectral imagery.

The Panel is worried about the continuation of Landsat-class measurements in the EOS-AM-2 era.

III.5. The Payload Advisory Panel recommends a careful reconsideration of the high resolution land remote sensing strategy for the EOS AM-2 era and beyond. This strategy must consider not only the scientific demands and potential payloads but also the issues of convergence and the contribution of international partners.

Amongst the issues for this discussion:

1. We are especially concerned with current arrangements for "reconciling" the needs of the Global Change research community and of the defense community with respect to the design of ALRSS. We are also particularly concerned about the high cost of the Landsat program, particularly Landsat 7. See also Recommendations III.1 and III.2.
2. Although ASTER provides visible and near infrared (VNIR) imaging with better than the requisite spatial resolution, it does not have the 200 km swath width that is needed to meet global imaging requirements.
3. The platform data handling capability must be consistent with the requirement for continuous pole-to-pole coverage. Some form of data compression may need to be considered to meet this objective. How this issue of data rate relate to the possibility of a hyperspectral instrument being include on AM-2 needs to be considered.
4. One of the unique attributes of ASTER is the acquisition of multispectral thermal infrared (TIR) imaging at high resolution. Such data are to be used for surface compositional mapping, observations of geothermal and volcanic phenomena, and land surface temperature/energy balance studies (thereby complementing the coarser spatial resolution observations to be acquired by MODIS). Retention of this capability may be desirable on AM-2. However, it is not necessary for such observations to be acquired with continuous global coverage; that is, a targeted capability is sufficient to meet the above measurement objectives. How should this be accomplished?

Evaluating the TIR contribution will be an important contribution to the discussion of the appropriate land observing program and instrument suites in the AM-2 era.

5. The hyperspectral imagery associated with the critical issues of canopy chemistry, as discussed, offers much promise in monitoring important components of the carbon cycle. It also could be crucial in understanding the land system in areas where chemical discrimination is important such as soil erosion, alpine watershed



hydrology (snow and ice characteristics), and the health of vegetation under chemical stress. It is important, however, to keep in mind that the swath and resolution requirements associated with hyperspectral imagery should not be mixed unnecessarily with those for continuation of Landsat-class measurements.

What is the appropriate hyper-spectral imaging strategy and instrument?

6. Convergence with respect to Japanese developments of ASTER-II and hyperspectral imagery needs to be examined.

IV. OCEAN AND LAND-ICE ALTIMETRY: EOS ALT

The science objectives of EOS Land-Ice Altimetry and EOS Ocean Altimetry dictate that these sensors be on separate spacecraft. Polar orbits with non-repeating or long-period repetition ground tracks are required for complete ice sheet surface topography, while lower inclination orbits with reasonable values for the mid-latitude and equatorial ground track crossover angles are required to achieve optimal recovery of ocean surface topography.

IV.1. The Payload Advisory Panel recommends that the Project proceed with plans for separate EOS spacecraft missions for land-ice altimetry and ocean altimetry.

A. OCEAN ALTIMETRY

The global sea surface topography currently being determined by the TOPEX/Poseidon Mission is of unparalleled accuracy and is providing a critically needed ability to monitor accurately the global oceans on a temporal resolution of 10 days. These data provide new opportunities for monitoring ocean phenomena and developing models to predict long-term Global Change.

Observation and Interpretation

The World Climate Research Program (WCRP) has identified ocean circulation as a key factor in determining global climate change. The most important oceanic processes affecting climate are those with spatial scales of the ocean gyres (> 1000 km) and ocean basins (> 5000 km). These processes include climatic variability such as *El Niño* Southern Oscillation (ENSO) and secular trends such as sea level rise and decadal changes in ocean circulation patterns. Both types of processes are quasi-stochastic in nature, and to understand them will require continuous observations for about 20 years. For example, the ENSO time scale is 3-5 years; sampling of five ENSO cycles to remove their effects on the long-term secular trend leads to the 20-year observational requirement. Continuity without significant gaps is essential to minimizing the effects of aliasing. Data with gaps enhance the danger of aliasing short-term variability into long-term trends.

The only observational tool that is capable of observing and monitoring the large-scale ocean circulation processes with adequate spatial and temporal sampling is satellite altimetry. The TOPEX/Poseidon Mission is the first altimetry mission to achieve the



measurement accuracy required for the study of large-scale ocean circulation processes relevant to Global Change issues.

Model Development

The set of TOPEX/Poseidon observations is crucial to the development of general circulation models (GCMs). The lack of an adequate coupled ocean-atmosphere GCM is one of the primary limitations in our ability to predict global environmental change. Hence, the construction of a comprehensive and realistic ocean circulation model is regarded by WCRP as a fundamental building block for Global Change studies. This requirement is the principal justification for the World Ocean Circulation Experiment (WOCE), which views the global topography determined by satellite altimetry as one of its primary satellite data streams.

From the modeling perspective, the time series of ocean surface topography can improve the numerical models' fidelity of the structure and accuracy of the parameters; they can also set conditions at successive time intervals that can be assimilated in models and thereby improve predictions. The TOPEX/Poseidon sea surface topography, when coupled with vector winds from scatterometer measurements and appropriate *in situ* measurements, provides the modeling community the information required to develop the requisite ocean models and to initiate the relevant ocean-atmosphere coupled model studies. As a consequence, it is imperative that this measurement series be continued past the current TOPEX/Poseidon Mission period.

Since the characteristics of the ocean circulation will be influenced by regional, process-driven effects, additional data will be required to improve our understanding of these processes. To achieve the high spatial and temporal scales required to support these process studies, measurements from other platforms (e.g., ERS-1, ERS-2, and GFO) will be a vital complement to the EOS Alt Measurements.

To complete the needed model developments, it is essential that sea surface topography measured from TOPEX/Poseidon continue for an adequate interval. The TOPEX/Poseidon Mission, extended to 5 years, is approximately half of the 10-year period specified in the original WOCE Objectives. It is imperative that we extend this crucial observational record to the EOS Alt era.

Bridging the Data Gap to EOS Ocean Alt

The TOPEX/Poseidon is exceeding mission specifications and providing a unique data set for studying ocean circulation. These important measurements for the study of Global Change must be continued.

IV.2. The Payload Advisory Panel recommends that the EOS Program and Project explore options for ensuring that the important measurements provided by the current TOPEX/Poseidon mission be continued to bridge the gap between the end of TOPEX/Poseidon and the launch of EOS Ocean Alt.

Two options are currently being considered.



1. *The TOPEX/Poseidon Follow-On (TPFO)*. This mission, to be conducted jointly with Centre National d'Etudes Spatiales (CNES), NASA, and NOAA and with a launch in 1998, represents the preferable option since it is designed to be compatible with actual TOPEX measurement performance. The TPFO option has the advantage of a commitment by CNES and NOAA for a sequence of satellite missions running through the year 2010. As a consequence, it seems logical that this series would simply replace or subsume the EOS Ocean Alt Mission in the 2002 time-frame.

This option must, however, face a significant budget hurdle. It would require a New Start and a budget commitment in 1995. This budget commitment would be external and in addition to the current EOS program.

2. *The GEOSAT Follow-On (GFO)*. This Mission is currently being developed by the United States Navy with a launch in 1996. For this to be a viable "Gap Filler" several changes would be necessary in order to meet the EOS Science Objectives:
 - a. Add dual frequency altimeter to correct for ionosphere
 - b. Transmit full wave-form data.
 - c. Boost sampling rate of altimeter to reduce noise.
 - d. Add laser retro-reflector cubes for ground tracking and calibration and validation.
 - e. Release all tracking data to the civilian community.
 - f. Keep in place the international TOPEX/Poseidon Science and Data Processing team.

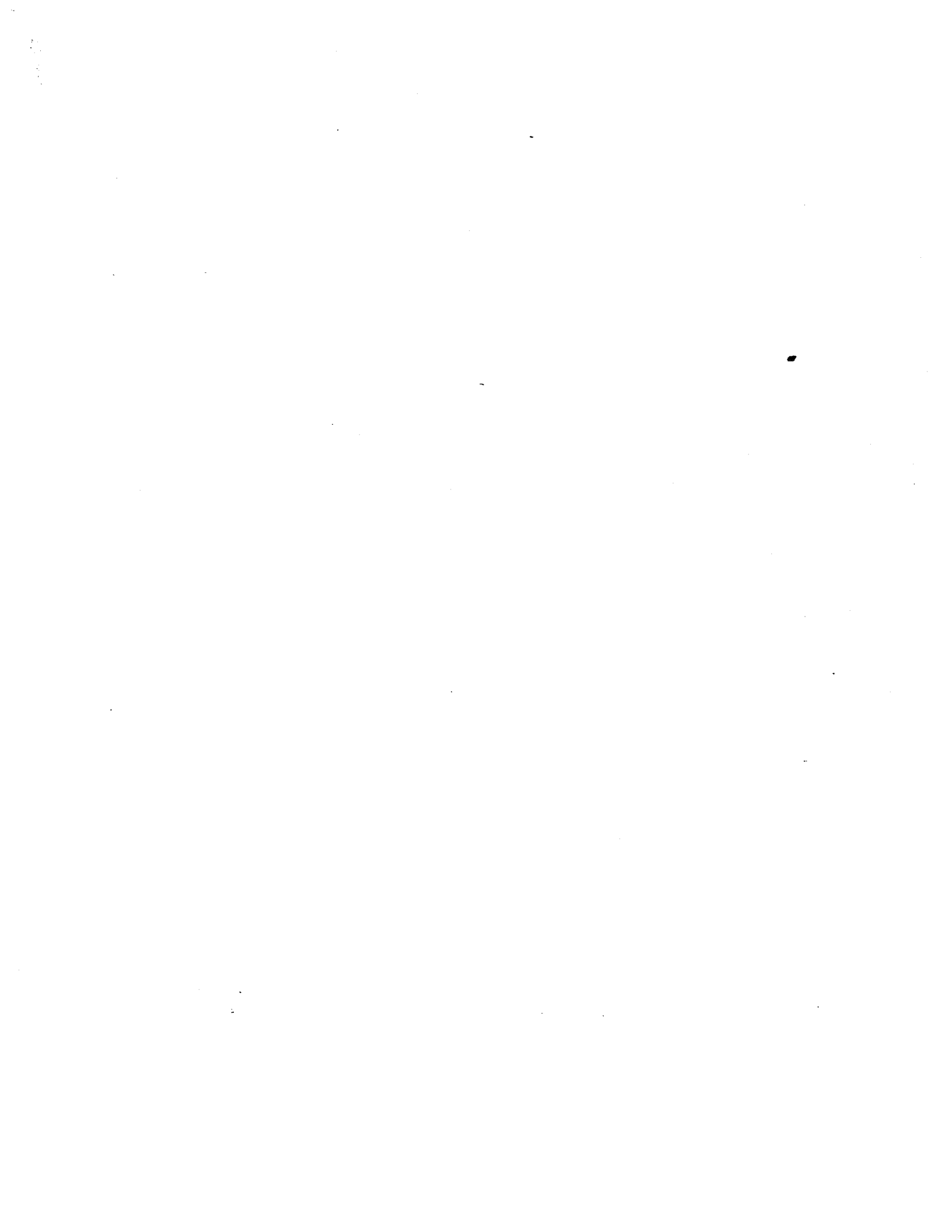
In addition, it would be preferable if the orbit were consistent with TOPEX/Poseidon.

The early flight of the GFO Option may require accelerating the EOS Ocean Alt Mission by one or two years to avoid another gap. This, however, offers potentially a significant, added benefit to the oceanographic community. Namely, the suggested improvement in GFO combined with reflights of GFO and flights of the EOS Ocean Alt Mission beginning in 2000-2002 would achieve, at least partially, the concurrent, multi-spacecraft implementation for ocean topography that the community has recommended. Finally, if NASA pursues this option, then the EOS Radar/Alt Mission would subsume the TOPEX Follow-On Mission. It seems appropriate to ask CNES if they would join the EOS Radar/Alt Mission in the same spirit as TOPEX Follow-On.

IV.3. The Payload Advisory Panel recommends that NASA vigorously explore the GFO option, because of the difficult budget environment. However, the TPFO option is the most desirable bridge to the EOS Ocean Alt.

EOS Ocean Alt

The performance specifications for EOS ocean altimeter missions for EOS Science should be commensurate with the TOPEX/Poseidon post-launch performance or better. This requires a dual-frequency altimeter, a high precision-tracking network of GPS and/or DORIS tracking systems, an SLR retro-reflector to allow definition of the long-term reference system and evaluation of the microwave altimeter bias drift, and a water vapor



radiometer. The orbit should be non-sun-synchronous with maximum inclination no greater than 72° to assure adequate intersection angles along the mid-latitude ground track.

B. LAND AND ICE ALTIMETRY

EOS Land-Ice Alt

The Geoscience Laser Altimeter System (GLAS) is the essential instrument for the IPCC key category of scientific uncertainty—"Polar ice sheets, which affect predictions of global sea level change." Commencement of GLAS measurements is extremely important to establish a baseline on global ice volume change and obtain essential data for forecasting sea level change.

IV.4. The Payload Advisory Panel recommends that strategies be explored for advancing the launch data of the GLAS instrument.

C. ADDITIONAL ISSUES

GPS Geoscience Instrument

In view of the continuing problems with GPS signal restriction (anti-spoofing), and the importance of the GPS to EOS Alt missions,

IV.5. The Payload Advisory Panel recommends that the GPS Geoscience Instrument (GGI) team focus on developing the codeless receiver technology.

The GGI team should evaluate the success of the NSF-funded METSAT Experiment and report to a future Payload Panel meeting on the feasibility of conducting the original GGI science objectives, particularly the prospect of measuring the global atmospheric temperature profile by multi-satellite occultation measurements.

The Payload Advisory Panel recognizes that since the GGI was not selected, that the team's future is in doubt. In any event, codeless receiver technology is an important area for further study.

Tracking and Data Relay Satellite System

The use of Tracking And Data Relay Satellite System (TDRSS) has a significant negative impact on the cost and design of small spacecraft. This could directly impact the EOS Alt Missions. Use of TDRSS on any particular EOS spacecraft should be based solely on its cost effectiveness for that spacecraft, considering both the space segment and the ground segment.

IV.6. The Payload Advisory Panel recommends that NASA assess the relative advantages and disadvantages of TDRSS, particularly for the smaller EOS platforms, before enforcing a hard TDRSS



requirement. The assessment must consider the full system, including both the space and ground segments.

V. THE EOS DATA AND INFORMATION SYSTEM

A. THE STATE OF THE SYSTEM

The long (three years) blackout surrounding the procurement of the EOSDIS Core System (ECS) contractor has ended, and in March 1993 NASA selected Hughes Applied Information Systems (HAIS) as the prime contractor. In the interval, EOS itself has changed substantially, hence the requirements of the information system have changed. The EOS Investigators Working Group (IWG) and its EOSDIS Advisory Panel have had their first views of the revised requirements, architecture, and design of EOSDIS.

We have high hopes for a system that will provide us with easy, affordable, and reliable access to EOS information and other appropriate Earth science data in a modern computing environment throughout the next two decades. However, we now see a danger that the system may not have essential attributes we had envisioned. There are fundamental flaws in the current architecture and design and in the plans for implementation, and the architecture and design are now changing. The currently proposed system lacks strong connectivity to the user community and does not embrace a problem-solving approach to EOSDIS development. Instead it is mired in details of fulfilling "requirements" without a high-level vision of the fundamental attributes of a successful data system. The Project, Contractor, and the proposed information system must improve their adaptability to function in a user-driven, evolutionary environment. If EOSDIS is to be successful, then its architecture, design, and implementation require substantial changes. Such change is now in progress.

With help from the scientific community, the EOSDIS Project and Contract must correct these faults. Time and resources are available, and the redirection of EOSDIS has begun.

B. CURRENT PROBLEMS WITH EOSDIS

1. *EOSDIS is not a distributed system.* Instead, it is a system of geographically dispersed elements with tightly centralized management, and the current Requirements Specification does not require logical distribution. Essential elements of a distributed system are missing:
 - a. clear interface specifications with alternative implementations being accepted if they meet the interfaces;
 - b. ability of the system to accept new developments not created by the project or the contractor;
 - c. clearly defined avenues for test marketing new ideas, products, and methods;
 - d. competition among elements to identify the best products and implementations;
 - e. dispersed responsibility, power, and resources where new ideas can be judged fairly, rather than having old ideas forced on the community by a management



with no exposure to the real difficulties faced by the user community and with insufficient experience of the multiple types of data, tools, and interfaces the community uses now and will use in the future.

Market forces are missing: an investigator who is dissatisfied with the system may abandon EOSDIS entirely and rely on other data sources. Indeed, given the inefficiency of the current process, individuals in the user community may find it easier to create their data products directly from Level 0 or Level 1 data themselves.

2. *EOSDIS is not an evolutionary system.* Instead its developers focus tightly on the near future, use tools and standards that are already obsolete, view “technology insertion” as synonymous with evolution, and need a better vision of the computing environment of the late part of this century and the early part of the next. The current Requirements Specification would produce a brittle system with obsolete properties and no flexibility to accommodate the new, interactive computing environment we face in our work. Evidence of the lack of ease of evolution is that the design changed little since 1990, in spite of important technological achievements in the architecture of distributed information systems and significant changes in how scientists access and use data.
3. *The current Requirements Specification is not clear.* To proceed, EOSDIS needs a clear, crisp, hierarchical description of the attributes of a successful EOSDIS, and the cost sensitivity of the requirements must be evident in the architecture and design. A particular problem for creators of scientific information is that the interfaces with the Science Computing Facilities and the Distributed Active Archive Centers (DAACs) are unclear. The planned editing process—consideration of “Review Item Discrepancies” (RIDs)—seems to us to bypass the fundamental structural flaws and overabundance of details in this document. Although the project has adopted the methodology of writing “Requirements” and appearing to refine them in a top-down fashion, the document that has resulted is not genuine top-down analysis of the type originally envisioned by the best practitioners of computer science. Clear evidence of this violation appears as detailed entities appearing before functions have been defined. In most cases, detailed architectural and design decisions have already been made without technical analysis.
4. *There is insufficient understanding of scientists' needs.* The developers are being driven by detailed requirements, with not enough sense of the overarching issues about information systems. The Project and Contractor have tried to define the users' needs as a tabulation of numbers that drive hardware purchases. They have given too little attention to these numbers' priorities, and they have not actively addressed the high-level requirements of a data system that users will embrace. Much of the effort spent on defining requirements appears fruitless and will contribute little to the development of a working EOSDIS. The performance



requirements in the statement-of-work are based on no substantive research or modeling.

5. *Version 1 does not build on Version 0.* With limited resources, the developers of Version 0 struggled to create a responsive system that embodies the spirit of independent development, autonomy among the elements, and user-driven functionality. Version 0 has evolved since 1990; the plans and concepts for Version 1 have changed little.
6. *EOSDIS lacks leadership in key positions.* Within EOSDIS there are people missing from key element-oriented positions such as technology assessment and data assimilation. Because of this, the understanding of how scientist use and produce data is inadequate. In addition, it inhibits the flow of information into the project since it is not clear with whom the user and outside expert should communicate. For example, experts in computing technology, with credentials comparable to those of the most prominent EOS investigators, have not had the opportunity to contribute to the architecture and design of EOSDIS.
7. *Interactions with the Project and Contractor are disappointing.* The commitment to the scientist as the "customer" seems to have disappeared; hence, they have too little knowledge of the characteristics and computing styles of Earth scientists. The EOSDIS Advisory Panel has found the Contractor and Project too hard to steer, and the members who serve on the Focus Teams complain that the Project is mired in details, when it should be adopting strategies to address important issues.
8. *The system is difficult to scale.* The current design and cost model are too conservative about the likely advances in computing technology over the next five years. In particular, the putative costs seem too sensitive to the floating-point operations needed to create the EOS standard products. The constraints are more likely to be the population of users served and the rate at which the system can deliver products to users. The system is too constrained to the current list of standard data products and does not appear versatile enough to incorporate new products that investigators will surely develop over the next two decades.
9. *There are too many system builders and operators.* The population of the group proposed to develop and operate the system seems large. By far the greatest expense in EOSDIS is the sum of the salaries for maintenance and operations, and the currently proposed staffing levels seem high. Modern computer systems require fewer personnel.

In summary, the country and the planet cannot tolerate an ineffective EOSDIS. The issues posed by Global Change are too vital. Spacecraft missions, such as the Mars Observer, have failed and will occasionally fail again because hardware components fail. In a ground data system, we can replace hardware and fix software bugs, so bad luck or the failure of a single component cannot cause the failure of EOSDIS. Instead, if EOSDIS fails, then Congress, the press, and the citizenry would blame NASA and the science community for



systematic, end-to-end mismanagement, and they would be correct unless we do something now. EOSDIS needs a dramatically different approach.

C. RECOMMENDATIONS

V.1. The EOS Payload Advisory Panel and the EOSDIS Advisory Panel strongly recommend that NASA work with the user community to fix EOSDIS. Furthermore, it must respond to comments from the National Research Council's Panel to Review EOSDIS Plans.

The task of building EOSDIS is enormous. There are no off-the-shelf solutions to the problems. Tremendous advances in the computing and networking environments complicate the technological issues. Users are diverse, and the way they use data and equipment changes rapidly. If the DAACs are slow to evolve, individual users will quickly have more processing power. For example, some UARS investigators now have workstations with more processing power and throughput than the central facility.

The link to the user community is crucial. Developing a working information system without user input is a prescription for failure.

The lifetime of EOS combines with the technological advances to further diversify how users will use data. In two decades, with a myriad of new data types, scientists will develop new diagnostic methods, and enhanced computing and networking will enable use of techniques that are now computationally prohibitive. These innovations will lead to identification of new, essential standard data products. Moreover, the system must plan for evolution on time scales longer than EOS. Long after the last EOS satellite, EOSDIS must provide the core for the data systems that follow.

Neither the EOS IWG nor its advisory panels nor the National Research Council can run EOSDIS. The Project and Contractor need a good understanding of the users and must be strong enough to implement EOSDIS. Otherwise, the advisory process is ineffective. However, the IWG and the broader user community must more actively drive the system. The Project and Contractor must develop mechanisms to incorporate users' ideas and systems into EOSDIS.

V.2. More specifically, the EOS Payload Advisory Panel and the EOSDIS Advisory Panel recommend the following actions, in priority order:

a. Rewrite the Requirements Specification.

Address the high-level attributes of a successful, distributed, evolutionary data system, whose fundamental purpose is to collect, process, archive, manage, and distribute data. Make the document crisp, sensible, and understandable, with an Executive Summary of no more than 4,000 words. Rank the requirements and be able to trace requirements to cost. Address the time scale at which requirements should be satisfied and the criteria for



continuing improvement in performance. Excessive detail is unnecessary. Reduce the volume of paper that the Contractor must deliver. The EOSDIS Advisory Panel is willing to review and edit draft versions.

b. Embark on studies of alternative architecture.

Draw in independent, outside expertise quickly to provide guidance on the redefinition of EOSDIS. Fund a few (at least two) small teams of independent computer scientists, Earth scientists, and systems integration experts to invent better, more easily evolved, truly distributed, more cheaply operated architecture and designs for EOSDIS. They should address the EOSDIS architecture and design from the perspectives of the information providers—scientists whose algorithms create scientific information from satellite data—and information users, who use this information to improve our understanding of the Earth. These studies should last about six months and should finish by early summer 1994.

c. Strengthen the awareness of users' needs within the Project and Contractor.

Identify specific, important problems and have the Contractor and Project work directly with investigators trying to address them (an example is the data assimilation effort at NASA/GSFC). Change the working definition of "user-driven" from a list of numerical specifications to having the developers work with the users, learn how they use data, enhance communication between them, and coordinate their expertise into EOSDIS. Enhance the standing and authority of the EOSDIS Project Scientist to improve the linkage between the Project and the science customers of EOSDIS.

d. Create a logical distribution of EOSDIS.

Build on Version 0, and empower the Distributed Active Archive Centers (DAACs) by distributing responsibility, power, and resources. Incorporate the Science Computing Facilities (SCFs) and Affiliated Data Centers (ADCs) into the information system, so that users can access special products that scientists create in the SCFs and other Earth science data in the ADCs.

e. Fund a vigorous and independent prototyping program.

It is essential that NASA have a more vigorous mechanism for developing and evaluating prototypes for EOSDIS elements, to foster advances in computing technology that could make EOSDIS a better system. The DAACs must support and foster these efforts, but the development activities must not be restricted to the DAACs. Academia and industry must participate too.

f. Focus on the needs of the user community.

Develop a user model and continuously improve the systems' functions to satisfy the users. Identify a few dozen groups of users from the DAACs and the data assimilation community and work with them in the early stages of development. The EOS IWG views



the science community's needs as similar to the needs of other users, for example those of high-school students, and the science community is willing to help NASA conceive and improve the system. Encourage and enable the value-added community to develop special products for educators, other federal agencies, local and state governments, and commercial applications.

g. Identify key people and assign responsibilities.

In both the Project and Contractor, identify those who are responsible for the execution of particular elements of EOSDIS. Work on problems of substance rather than provide excessive documentation about the execution of the contract. At this stage in the development, EOSDIS does not need an army. Instead it needs a small cadre of experts who are familiar with computing technology, integration of systems, and users' needs. Hire a first-rate computing technologist, someone with stature in the academic computer science community, to advise Project and Contractor. Do not ramp up staffing too quickly. Each head of an EOSDIS element must be the best person available, and the Contractor must pay more attention to the quality of the new hires.

h. Become more aware of non-governmental data systems.

Among the science community and, for example, the financial industries are many data systems that try to address issues similar to those in EOSDIS—large data volumes; multiplicity, complexity, and heterogeneity of data sets; integrity of data and real-time processing; and large, distributed, remote user communities. Program, Project, and Contractor should examine these systems and apply lessons to EOSDIS.

i. Increase coordination with other NASA projects.

There is a broad governmental thrust to improve computing and information systems to handle better the glut of data that faces the nation. It is essential to work in coordination with these efforts, especially the High Performance Computing and Communications Initiative.

D. CLOSURE

For the next few months, we need to be patient and give the Project and the Contractor a chance to begin to solve these problems. They have been working with a compressed schedule, and they have responded too conservatively to the NASA Administrator's focus on control of cost and schedule. The comments of the science community, during and after the System Requirements Review in mid-September, have shocked them into action. We need to have confidence that they can respond and to give them a chance.

We will not wait indefinitely. NASA must fix EOSDIS soon. If we do not see substantial improvement by January 1994, if we do not have confidence that EOSDIS is on the road to recovery by then, then we must take drastic steps.



Therefore, we proposed an informal system review—revised requirements, cost breakdown, architecture, design, and plans for maintenance and operations—before the next meeting of the EOS IWG, which is scheduled for January 11-13, 1994. The system review occurred on December 13-14 with members of the EOSDIS Advisory Panel (about a dozen persons) and a larger group of representatives from NASA HQ, EOSDIS Project, the Contractor, and the information science community. Based on this review, the EOSDIS Advisory Panel will evaluate the commitment and leadership of the EOSDIS Project and Contractor to evolution, distribution, creativity, excellence, and economical operation. Our initial assessment is positive.

V.3. At the January 1994 IWG meeting, the IWG will hear a report from its EOSDIS Advisory Panel and make recommendations to NASA about directions for EOSDIS.



APPENDIX I

MEMBERS OF THE EOS PAYLOAD ADVISORY PANEL



APPENDIX II

PARTICIPANTS AND THE AGENDA



EOS PAYLOAD ADVISORY PANEL MEETING

October 4-6, 1993

EOS Payload Advisory Panel

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EOS PAYLOAD ADVISORY PANEL MEETING

October 4-6, 1993

EOS Payload Advisory Panel

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EOS PAYLOAD ADVISORY PANEL MEETING

October 4-6, 1993

EOS Payload Advisory Panel

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EOS PAYLOAD ADVISORY PANEL MEETING

October 4-6, 1993

EOS Payload Advisory Panel

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10/1/93

AGENDA

EOS Payload Advisory Panel Meeting October 4-6, 1993

DAY 1, Monday, October 4, 1993

- | | | |
|-------|---|----------------------|
| 08:00 | Welcome and Charge | B. Moore |
| 08:15 | View from Mission to Planet Earth | S. Tilford |
| 08:45 | View from OSTP | J. Gibbons/R. Watson |
| 09:15 | View from OMB | J. Payne |
| 09:45 | View from NOAA | T. Durham |
| 10:15 | Break | |
| 10:45 | View from the EER/Global Change Board | V. Ramanathan |
| 11:15 | View from Space Studies Board/CES | J. McElroy |
| 11:45 | View from Europe/ESA | C. Readings |
| 12:15 | View from Japan | Y. Haruyama |
| 12:45 | Lunch | |
| 14:00 | Summary of Morning and Review of the Issues | B. Moore |
- Coordination and Convergence
 - ESA's ENVISAT and EOS Chemistry
 - METOP-1, NOAA-OPQ, DMSP, EOS
 - LandsAT, SPOT, HIRIS-2
 - GEOSAT Follow-On and EOS ALT
 - CHEMISTRY
 - DATA BUYS
 - AM-2/TES/CHEMISTRY
 - SUMMARY: Role of the Payload Advisory Panel



DAY 1, Monday, October 4, 1993 (continued)

14:15 Convergence & Coordination: ESA's ENVISAT -
EOS Chemistry*

- ESA's ENVISAT (1 hour) C. Readings/Pis
- EOS CHEMISTRY (3/4 hour) M. Schoeberl/J. McNeal/Pis

* Note: ENVISAT and EOS PI's are requested to be prepared to discuss as needed the capabilities and requirements for their instruments.

16:00 Break

16:30 TES/EOS AM-2/CHEMISTRY J. McNeal

- Status
- Mission: AM-2 Platform or ENVISAT-II or Chemistry
- Connect with HIRIS-2: Platform Resources
- Near-term actions
- Discussion
- Recommendation Guidelines

17:00 Discussion of ESA's ENVISAT and EOS Chemistry
- -- Recommendation Guidelines

18:00 Adjourn

19:00 EOS Dinner

DAY 2, Tuesday, October 5, 1993

08:00 Announcements B. Moore

08:15 EOS-PM-1 C. Parkinson

- MHS/AMSU-B
- ~~Other~~
- Discussion
- Recommendation Guidelines

09:00 Convergence & Coordination: METOP-1, NOAA-OPQ, DMSP, EOS

- Overview (5 min) B. Moore
- ESA/EUMETSAT/METOP-1 (40 min) M. Langevin
- DMSP/NASA/NOAA N' and OPQ (40 min) W. Townsend
- Summary (5 min) B. Moore

10:30 Break



DAY 2, Tuesday, October 5, 1993 (continued)

- 11:00 Discussion of Convergence and Coordination
- METOP-1; NOAA-OPQ, DMSP, EOS
 - Convergence: DoD
 - Convergence: NASA
 - Convergence: ESA/EUMETSAT/METOP-1
 - Role(s) of the NOAA Polar Platforms
 - Recommendation Guidelines

12:30 Lunch

- 13:30 HIRIS Report and LandsAT A. Goetz/J. Aber/A. Janetos
- Status
 - Near-term action
 - Discussion
 - Recommendation Guidelines

- 14:45 EOS ALT-Radar M. Van Woert/C. Koblinsky
- Status
 - Overlap with GEOSAT-Follow On
 - Possible role of NOAA
 - Near-term actions
 - Discussion
 - Recommendation Guidelines

15:30 Break

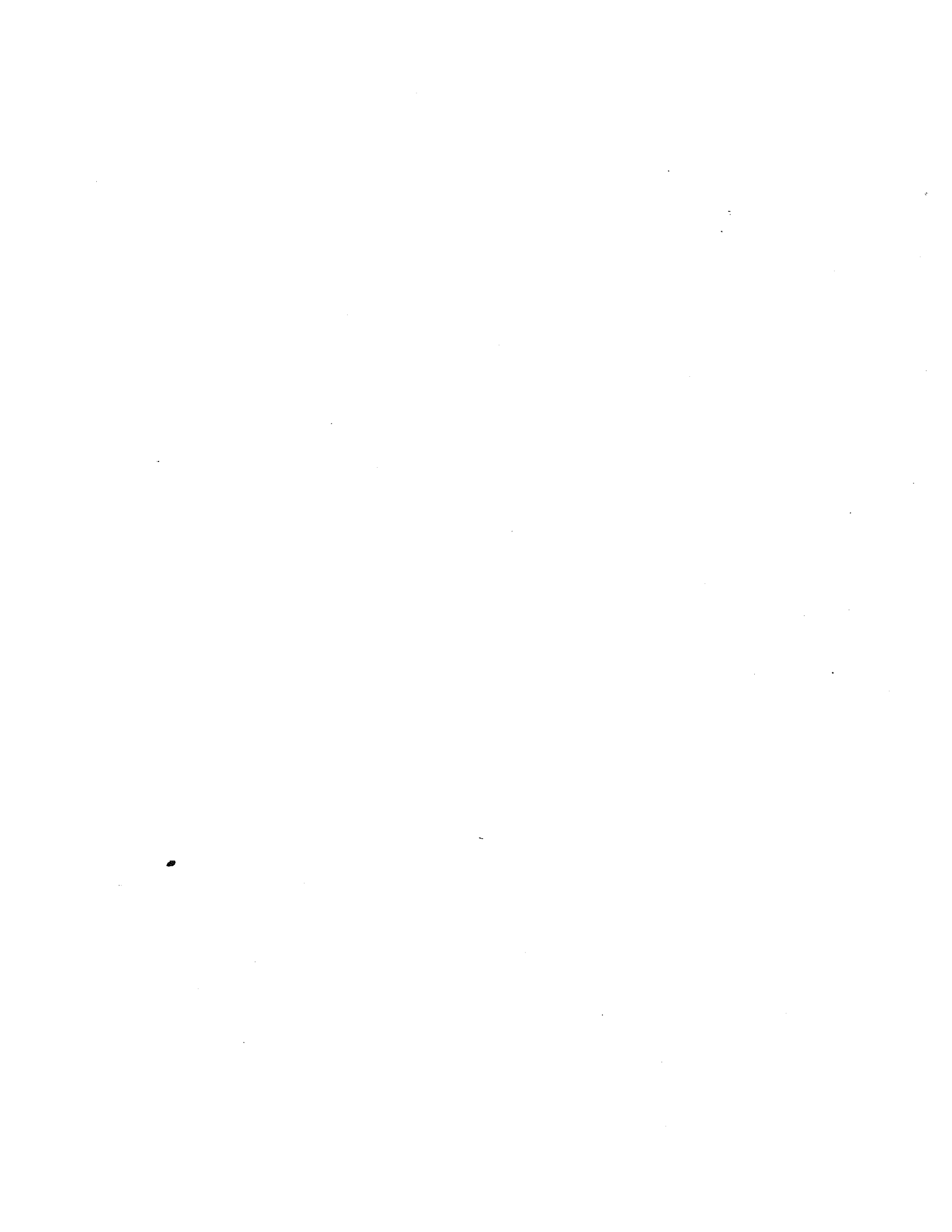
- 16:00 EOS ALT-Laser M. Baltuck/J. Zwally
- Status
 - Near-term actions
 - Discussion
 - Recommendations Guidelines

- 16:45 ~~EOS DIS~~ UPDATE D. Butler/J. Dalton/J. Dozier
- Status
 - Near-term actions
 - Discussion
 - Recommendation Guidelines

17:30 Formation of Writing Teams: Guidelines Review

18:00 Adjourn

Writing Teams in informal evening session



DAY 3, Wednesday, October 6, 1993

08:30 Announcements and Status Check

08:45 Writing Teams in session

10:30 Writing Team Reports

- EOS Overview
- EOS Chemistry
- Convergence: METOP-1, NOAA-OPQ, DMSP, EOS
- HIRIS/LandSAT
- EOS ALT
- AM-2/TES

13:30 Adjourn



APPENDIX III

TOTAL SOLAR IRRADIANCE MONITORING REPORT



Total Solar Irradiance Monitoring
Report of the Atmospheres Panel to the Payload Panel
November 1993

Dennis L. Hartmann, Panel Chairman
B.R. Barkstrom
D. Crommelynck
P. Foukal
J. E. Hansen
J. Lean
R.B. Lee III
M.R. Schoeberl
R.C. Willson

1.0 Executive Summary

1.1 *Variations of total solar irradiance that have been directly observed to date are smaller than the anthropogenic climate forcing and are too small to have a measurable effect on climate. Total solar irradiance is nonetheless a critical control of climate and needs to be monitored in order to assess observed and predicted climate changes.*

Changes of total solar irradiance (TSI) are suspected of being one of the causes of past global climate changes on decade to century time scales, but proof of this is lacking because of a long-term record of TSI with sufficient precision. Current active cavity radiometer designs are able to measure the total solar irradiance (TSI) with an absolute accuracy of about $\pm 0.35\%$. The relative precision of existing measurements is believed to be much better, perhaps about $\pm 0.01\%$, and future measurements may have relative precision as good as ± 50 ppm. Simultaneous measurements from several instruments show consistent variations of TSI during the 11-year solar cycle with an amplitude of about 0.1%. This amount of solar irradiance variability is too small to cause a practically significant or measurable variation in global surface temperature. The equilibrium response to steady forcing of this magnitude would be 0.1 to 0.2K and the transient response to periodic 11-year forcing would be less than half of the equilibrium response to steady forcing. The magnitude of the anthropogenic greenhouse gas climate forcing calculated over the period 1750 to 2000 is about 2 W/m^2 , or about eight times the magnitude of the climate forcing associated with the 11-year solar cycle. The anthropogenic greenhouse gas forcing is expected to double again in the next 50 to 75 years (Shine, et al., 1990). Solar irradiance changes during the next few decades are unlikely to cause a climate forcing as large as that from anthropogenic greenhouse gases, ~~if the latter~~ continue to increase rapidly. The net anthropogenic climate forcing may be less than that associated with greenhouse gases, however, since evidence suggests that climate forcings associated with anthropogenic changes in aerosols and clouds may have offset as much as half of the anthropogenic greenhouse enhancement that has occurred up to the present time. Whatever the anthropogenic climate forcing, without measurements of the natural climate forcing from solar irradiance changes, it will be difficult to assess the implications of observed climate changes.

1.2 *An effort to measure variations in total solar irradiance on time scales longer than an 11-year solar cycle should be maintained.*

Since the 11-year cycle is the largest regular variation in solar activity, and its effect on total solar irradiance is small, it is tempting to conclude that TSI variability is not of major concern for climate variations over the next 100 years. The primary worry

with this conclusion from the perspective of global climate change prediction is that TSI variability on longer time scales than the 11-year cycle might be larger in magnitude and would cause a significant climate response that would affect the interpretation of observed temperature trends and the strategies that might be developed to avert or mitigate the consequences of a human-induced climate change. Our knowledge of TSI variability and its relationship with solar activity is, after all, based on measurements over only one complete solar cycle. Even if TSI variability on this time scale is small, if it is not measured an uncertainty will remain about its potential influence which might slow the development of effective policies regarding global climate change.

1.3 The best strategy for measuring long-term trends in total solar irradiance is to continue the sequence of overlapping measurements with instruments specifically designed to measure total solar irradiance with absolute calibration.

Because the precision, but not the accuracy, of TSI measurements is sufficient for long-term monitoring, detection of long-term trends requires substantial overlap between succeeding instrument packages so that they can be calibrated against each other and provide a record of TSI deviations. To retain this precision against instrumental degradation, each package requires multiple detectors. With the currently planned schedule for launches of ACR instruments, a gap in the record will likely occur between the end of UARS/ACRIM measurements and the SOHO/VIRGO measurements sometime in the 1994-6 interval and again between SOHO/VIRGO and the planned launch of the ACRIM on EOS/CHEM in about 2002.

1.4 Indices of solar activity are well correlated with total solar irradiance over the 11-year solar cycle, but the precision of these indices and their statistical relationships with TSI are probably inadequate for long-term trend detection.

Since some quantitative measures of solar activity that can be accurately measured from the ground are well-correlated with TSI, it is reasonable to ask whether these data might be used to bridge gaps between more direct measurements of solar energy output variations. This strategy will need to be employed if the required overlap between direct measurements cannot be achieved, but it is questionable whether the required high level of precision can be maintained in this way. On a fundamental level, the physical relationships between solar activity indices and TSI are not understood, so that the relationships are purely statistical in nature. Also, it is unclear whether the relationships between solar activity indices and TSI that are obtained from observing the 11-year cycle are the same as those that would apply for longer-term solar activity and solar irradiance variability, which may result from different physical processes within the sun. On a more practical level, the precision inherent in the statistical relationships may be less than the precision required to measure the very small trends that are expected. It is also unlikely that the solar activity indices themselves possess the high precision and stability required for TSI trend detection (e.g. ~0.01% or less over the gap interval).

2.0 Total Solar Irradiance: A Fundamental Control on Climate

The total solar irradiance (TSI) or solar constant is the total radiative energy flux density reaching the mean position of Earth from the sun. It is estimated to be $1367 \pm 2 \text{ W m}^{-2}$. The total solar irradiance is by far the dominant source of heat for driving the energy and hydrologic cycles of Earth's climate system. A 2% change in solar constant gives a thermal forcing for the climate system that is about equivalent to a doubling of atmospheric carbon dioxide.



$$\frac{TSI}{4}(1 - Albedo) \times 0.02 = 4.8 W m^{-2}$$

Direct observations of total solar irradiance are limited to only a little over one solar cycle, during which the solar energy output variations were measured to be about 0.1%, which is too small to produce a measurable temperature change. Indices of solar activity show variations on longer time scales of 88 years or so, which are on the same time scale as the 100 year horizon for global greenhouse gas warming. If the total irradiance changes on these time scales are larger than those on the 11-year sunspot cycle time scale, then significant surface temperature changes could be attributed to total solar irradiance variations. Larger solar variations on longer time scales are suggested by empirical studies (Friis-Christensen and Lassen, 1991, Hoyt and Schatten, 1993). These potentially larger solar-forced climate changes might affect the detection of global climate changes caused by human actions, the assessment of future climate trends, and the policies we may develop to mitigate or adapt to them.

3.0 Direct Observations of Solar Constant Variability

3.1 Radiometers for TSI Monitoring

Currently instruments for measuring the total energy output of the sun consist of unfiltered thermal detectors with both sun-viewing and reference cavities and electrical heat substitution to maintain constant instrument response (We can call this an active cavity radiometer, or ACR for short). Such technology offers an apparent absolute accuracy of about $\pm 0.35\%$, but with substantially better precision of about ± 50 ppm (Willson, 1993, Crommelynck, 1993) Current designs such as ACRIM have three instruments in one package. The first instrument views the sun continuously, while the other two are exposed only infrequently and are used to calibrate the first which degrades slowly in response to its exposure to solar ultraviolet radiation.

3.2 Available Measurements

ACR instruments (or related designs such as the Hickey-Freidan radiometer on Nimbus-7) have been flown on a number of satellite missions. The longest continuous record is the 14 year record of the Nimbus-7 ERB which began in late 1978 and ended in early 1993. Overlapping this record are the Solar Maximum Mission (1980-1989) and the Earth Radiation Budget Experiment (1984-present) TSI measurements. An ACR is currently operating on the UARS satellite. The measurements from these instruments and a timetable of planned missions are indicated in Figure 1. The mean values of the solar constants inferred differ by $7 W/m^2$ or about 0.5%. They each indicate a very similar magnitude for the variation of total solar irradiance over solar cycle of about 0.1%, however, so that if the offsets are removed the remaining differences are at about the 20 ppm level. This comparison indicates that the relative precision of measurement is much greater than the absolute accuracy. The primary constraint on absolute accuracy for current ACR instruments seems to be knowledge of the aperture area, and thermal perturbations by the field of view limiter (e.g. Crommelynck, 1989).



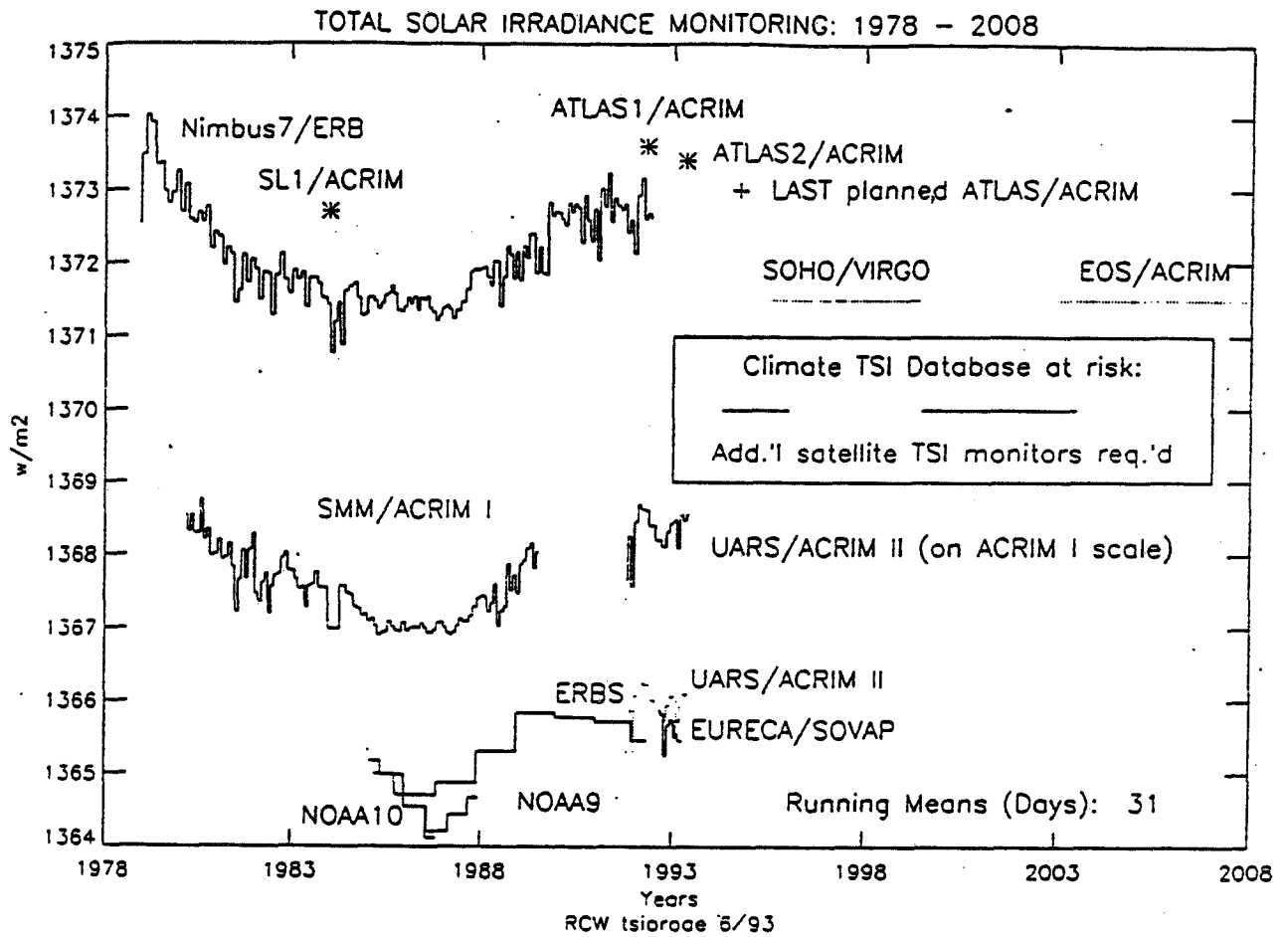
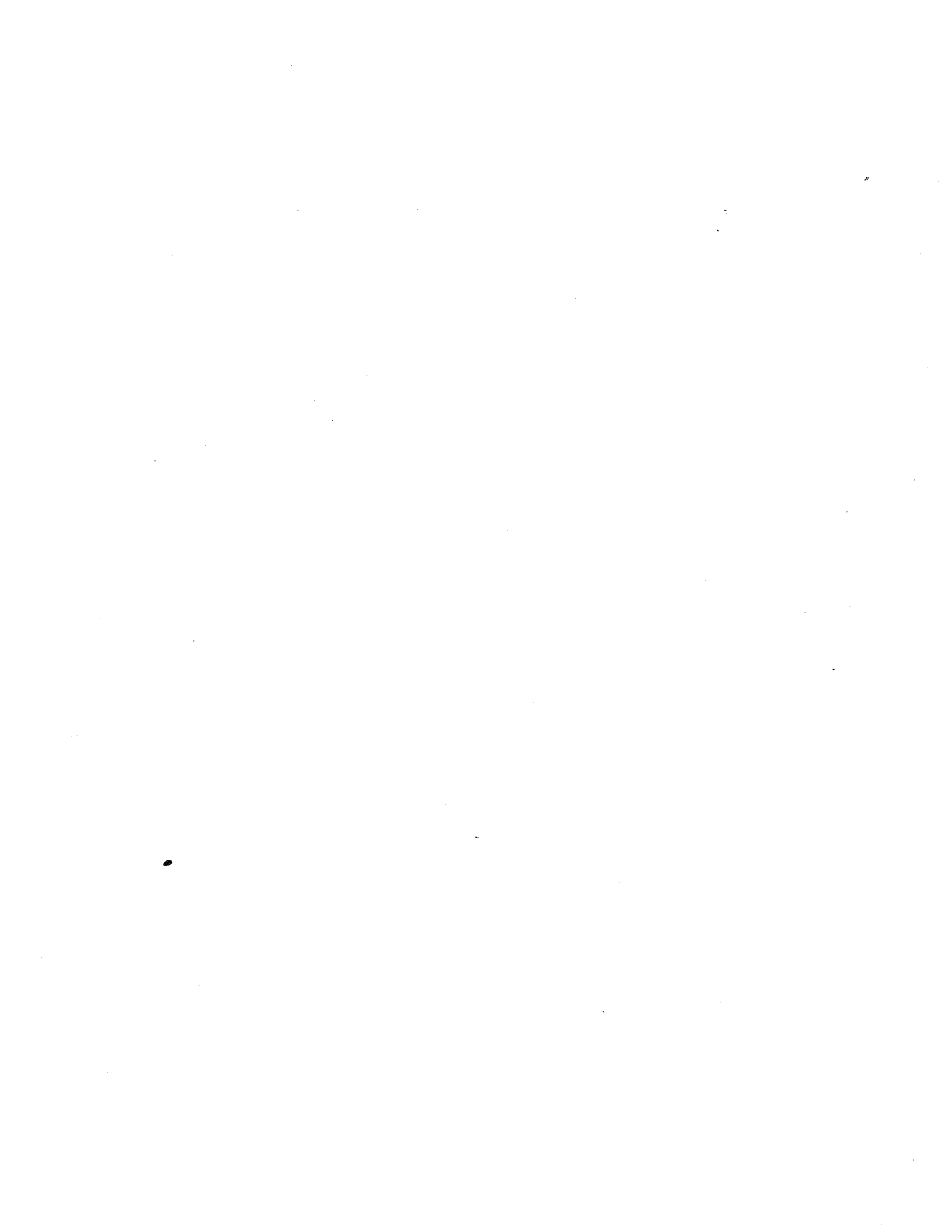


Figure 1. Measured total solar irradiance from 1978 through 2009 showing 31-day running mean measurements taken from orbit and planned future mission launch dates. (From Willson, 1993).



These intercomparisons suggest that long-term trend measurement with a relative accuracy considerably better than 0.1% could be achieved with a series of ACR instruments, if the flights of the instruments overlap sufficiently in time to allow the biases between instruments to be measured. By adjusting the data to remove the bias differences, a long time-series of TSI variations with an unknown but unchanging bias can be established. This "overlap strategy" has been proposed as one means measuring solar constant trends that may exist at time scales longer than one solar cycle, beginning with the launch of the Nimbus-7 satellite in 1978.

3.3 Future Measurements and the Overlap Strategy

The strategy for long-term measurement of total solar irradiance requires overlap between succeeding ACR instruments, so that the biases between instruments to be accounted for, thereby producing an estimate of long-term deviations in TSI that is independent of the uncertainty in absolute accuracy. As can be seen in Figure 1, it is likely that the string of overlapping ACR measurements begun with Nimbus-7 ERB will be broken by gaps between the UARS/ACRIM and SOHO/VIRGO instruments in 1994-6 and again between SOHO/VIRGO and the planned EOS/ACRIM launch on EOS/CHEM in 2002. Without overlap between past and future instruments, a record of long-term solar irradiance variations cannot be built upon the record available from the current generation of instruments.

4.0 Empirical Relationships between Solar Activity Indices and Solar Constant

A number of studies have shown that indices of solar activity such as photometric sunspot index, 10.7 cm flux (Lee, et al., 1993), He 1083 line width (Willson, 1993a, Willson and Hudson, 1991), Mg c/w ratio (Pap and Fröhlich, 1988, Willson, 1993b), and others (Livingston, et al., 1991, Livingston, et al., 1988) have been well correlated with total solar irradiance over the period during which TSI has been observed. These correlations have been used to develop empirical models that predict TSI based on one or more of these indices of solar activity. These empirical models can represent the variation of TSI over the last solar cycle, although they obscure some of the higher frequency variability and usually underestimate the TSI at the peak of solar activity. The typical goodness of fit of these regression models is about 0.03 to 0.05%, compared to an 11-year solar cycle signal of about 0.1%, and this is based on only one solar cycle.

Some of these empirical models have been used to extrapolate TSI variability into the past. For example, (Foukal and Lean, 1990) have used indices of sunspot dimming and facular brightening to estimate variations of TSI over the period 1875-1988. The variations were generally smaller than the observed variation of the last solar cycle of 0.1%. Analyses of the effect of observed or expected TSI variations on climate have indicated that they should be small compared to changes expected from anthropogenic or other natural forcings over the next century (Hansen and Lacis, 1990, Kelly and Wigley, 1992). The main uncertainty on the century time scale seems to lie with possible variations on longer time scales associated with, for example, the 80-year Gleissberg cycle in sunspot abundance (Baliunas and Jastrow, 1990). Lean, et al., (1992) have used the linear relationship between Ca II emission and TSI observed over the last solar cycle to extrapolate a solar constant that would apply for the conditions of minimal activity that are believed to characterize the Maunder Minimum period from 1645 to 1715. They estimate a TSI for that period that was 0.24% less than the average over the most recent solar cycle, which would give an equilibrium surface temperature response of from 0.2 to 0.5°C. A solar constant change of this magnitude would give a climate response that would be of practical significance.



The question arises whether the empirical relations between solar activity indices and TSI that have been used to estimate the possible magnitude of past and future TSI changes can be used to bridge potential gaps in the record of direct measurements of TSI. This is a questionable strategy for several reasons. First, the relationships are primarily statistical and based on slightly more than one 11-year solar cycle. It is unclear whether the statistical relationships so far derived are based on sound physical relationships, and whether these statistical relationships would be the same for 11-year cyclic variability and for possible longer-term variations in solar energy output. Also, it is probably true that the regressions between TSI and solar activity indices are not precise enough to provide the great precision necessary to measure small trends over several decades. Finally, the stability and precision of the indices for solar activity may not be adequate for detection of the small trends expected. For example, Tapping(1993) estimates the current precision of 10.7 cm flux measurements to be 0.5% (Tapping and Charrois, 1993).

5.0 Future Developments in Solar Irradiance Measurements

Improvements such as cryogenic radiometers (Foukal, et al., 1991) or precision laser measurement of apertures(Fischer and Stock, 1992) offer the possibility to increase the absolute accuracy available from satellite instruments. For a similar aperture size field of view limiter errors are much less in cryogenic radiometers, so more accurate knowledge of aperture area would be more fruitful than for uncooled radiometers, for which uncertainties associated with field of view limiter temperature and aperture area are of the same order. Such improvements would be of value, but would not help to connect past measurements with future ones, if a gap occurs in the measurement record before these improved instruments can be placed in service. Moreover, the added complexity and limited life of cryogenic radiometers would make the long-term continuous monitoring required more difficult and expensive.

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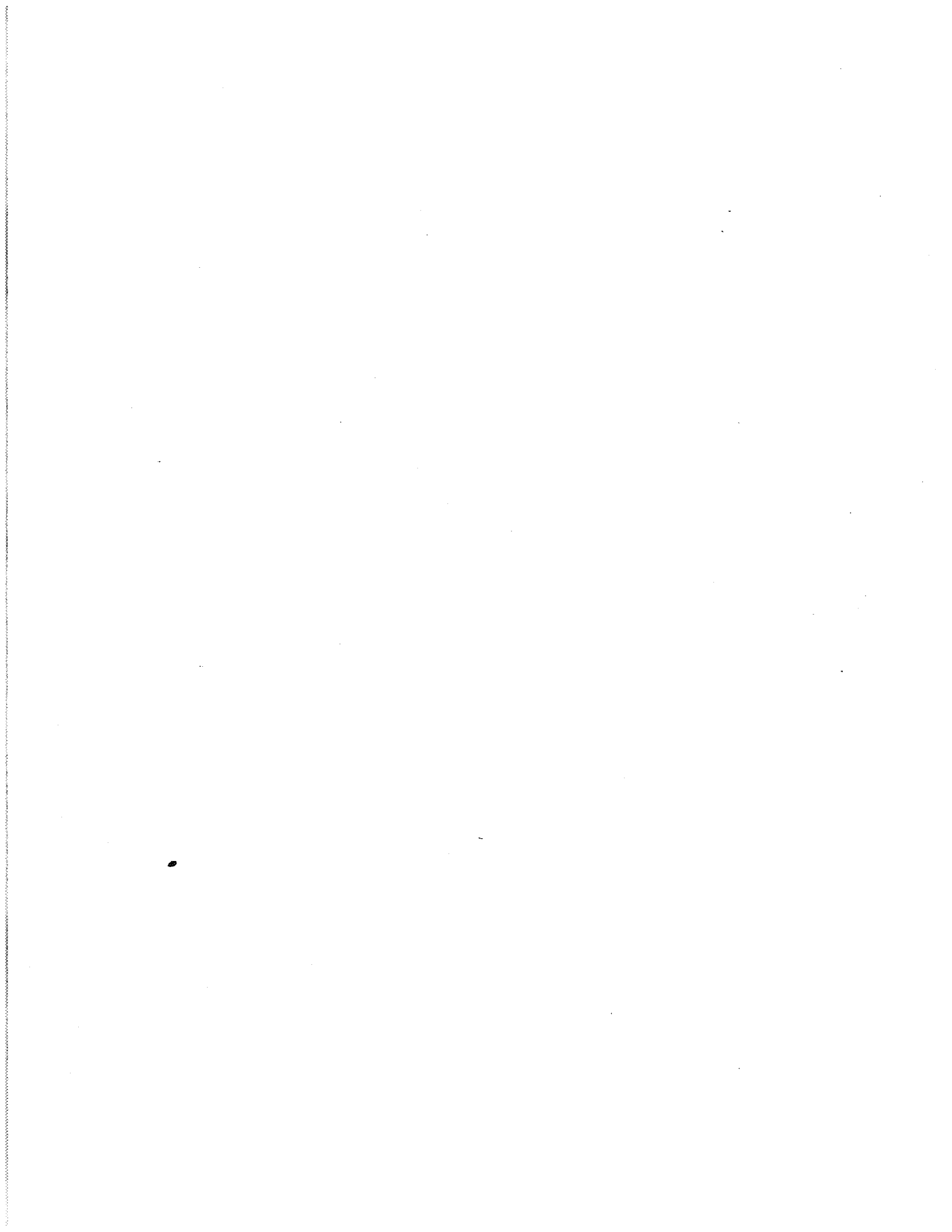


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APPENDIX IV

RESULTS FROM THE ACCELERATED CANOPY CHEMISTRY PROGRAM



RESULTS FROM THE ACCELERATED CANOPY CHEMISTRY PROGRAM AN INTERIM REPORT

Following the October 1991, Easton meeting of the Payload Advisory Panel, the IWG requested the HIRIS Team and Ecosystem Dynamics and Biogeochemical Cycles Branches to perform a 'fast-track' assessment of the capability of high-spectral resolution spectroscopy to measure canopy chemistry from space. Professor John Aber presented the report, whose digest follows.

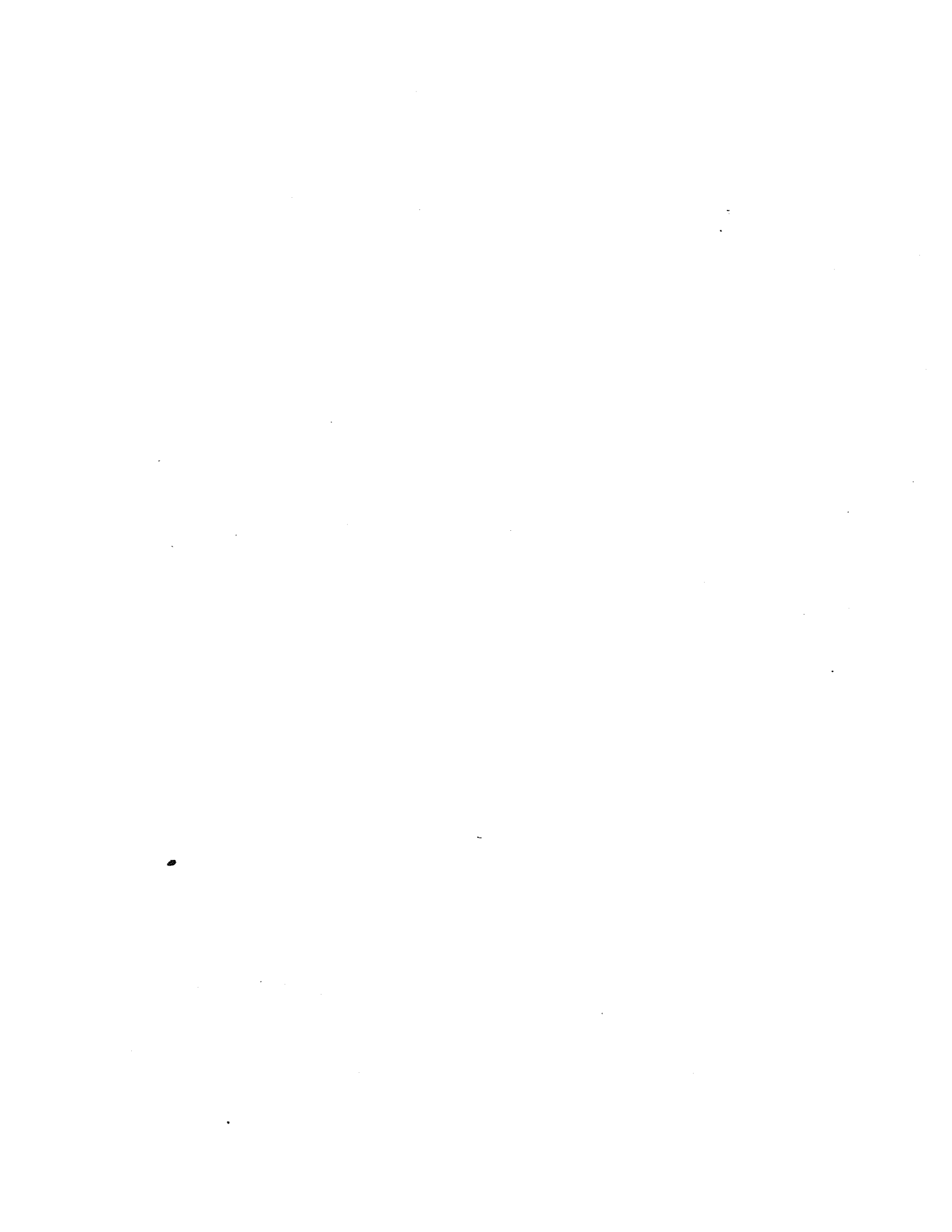
RESULTS FROM THE PROGRAM

1. The Program reaffirmed that nitrogen, lignin and cellulose signals are present in dried, ground foliage. Accuracy of NIR methods are limited only by accuracy of wet chemical methods. Analytical error (estimated by repeated analyses of same sample) is 1/3 to 1/8 of wet chemical techniques.
2. Showed that signals are also present in fresh, whole foliage. Signal is not diminished in presence of water, cuticle, and intact leaf structure.
3. Demonstrated that nitrogen and lignin concentrations of whole forest canopies can be determined from AVIRIS data when ground data are available within the scene. Information is present in radiation upwelling from canopy.
4. Demonstrated that wavelengths used in one AVIRIS scene to extract information on nitrogen concentration also contain similar information in other scenes, even when atmospheric corrections are not yet of highest quality. There is consistency in wavelengths between scenes used to extract chemical information.
5. Identified similar end-member spectra by two techniques:
 - a) consecutive digestion with spectral analysis by linear mixing models, and
 - b) analysis of pure materials.A third method, deconvolution by convex geometry, is being tested.
6. Exercised 1D radiosity model and 3D ray tracing model. Both suggest that :
 - a) leaf-level signals should propagate through canopies,
 - b) these signals can be detected without significant modeling corrections in canopies with Leaf Area Indices (LAI) above 2- 3, and
 - c) modeling corrections can be made in sparser canopies.

Although sparse or patchy vegetation remains difficult to analyze, only a small fraction of global terrestrial carbon storage and Net Primary Production (NPP) occurs in such systems.

REMAINING CHALLENGES FOR THE SECOND YEAR OF THE PROGRAM

1. Developing absolute cross-prediction of canopy chemistry for several AVIRIS scenes requires:
 - a) improve atmospheric correction by convex geometry end-member analysis, and
 - b) an overall improvement of atmospheric correction models.



2. Testing limits of generality in individual leaf and whole canopy calibrations. Specifically the issue of the generality versus precision with increasing number of species and sites.
3. Selecting the optimum set of wavelengths for determination of nitrogen, lignin and cellulose for both laboratory experimentation and field observations.

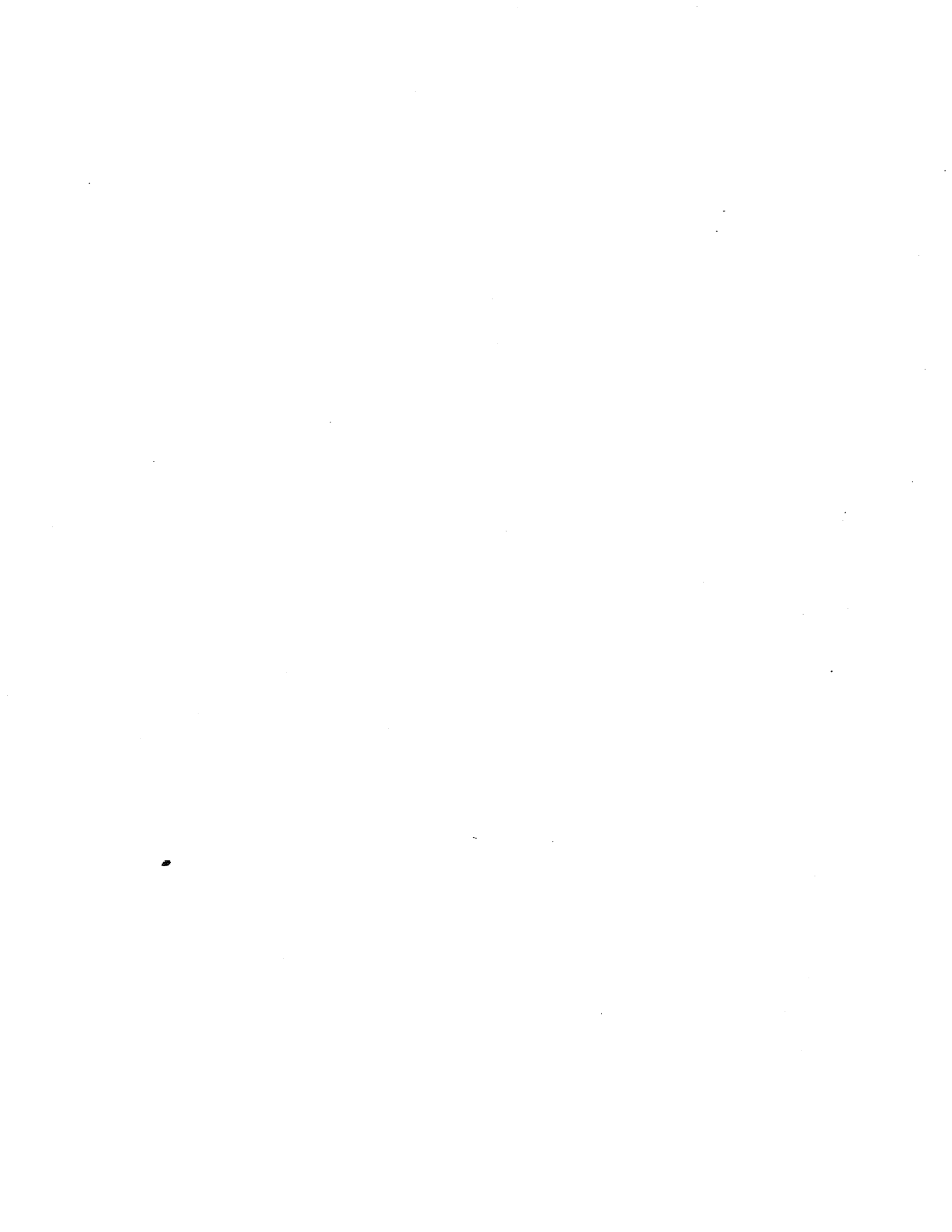


ACRONYM LIST



ACRONYMS

ACCP	Accelerated Canopy Chemistry Program
ACRIM	Active Cavity Radiometer Irradiance Monitor
ADEOS	Advanced Earth Observing System
ADS	Affiliated Data Center
AIRS	Atmospheric Infrared Sounder
ALT	Altimeter
AMSU	Advanced Microwave Scanning Radiometer
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATLAS	Atmospheric Laboratory for Applications and Science
AVHRR	Advanced Very High-Resolution Radiometer
AVIRIS	Airborne Visible and Infrared Imaging Spectrometer
CI	Chemistry International Instrument
CERES	Cloud and Earth's Radiant Energy System
CNES	Centre National D'Etudes Spatiales
DAAC	Distributed Active Archive Center
DMSP	Defense Meteorological Satellite Program
DoD	Department of Defense
DORIS	Determination d'Orbite et Radiopositionnement Integres par Satellite
ECS	EOSDIS Core System
EOS	Earth Observing System
EOSDIS	EOS Data and Information System
ENSO	El Nino Southern Oscillation
ENVISAT	Environmental Satellite
ERBE	Earth Radiation Budget Experiment
ERS	European Remote Sensing Satellite
ESA	European Space Agency
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FPAR	Fraction Photosynthetically Active Radiation
GCM	General Circulation Model
GFO	GEOSAT Follow-On
GGI	Geoscience Instrument
GLAS	Geoscience Laser Altimeter System
GPP	Gross Primary Production
GPS	Global Positioning System
GSFC	Goddard Space Flight Center
HAIS	Hughes Applied Information Systems
HIRDLS	High-Resolution Imaging Spectrometer
INPE	Brazilian National Space Agency
IPCC	Intergovernmental Panel on Climate Change
IWG	Investigator Working Group
LAI	Leaf Area Index
LIRIS	Loral Infrared and Imagery Systems Inc.
MERIS	Medium-Resolution Imaging Spectrometer
METOP	Meteorological Operational Satellite
METSAT	Meteorological Satellites-
MHS	Microwave Humidity Sounder
MIMR	Multifrequency Imaging Microwave Radiometer
MISR	Multiangle Imaging Spectro-Radiometer
MLS	Microwave Limb Sounder



MODIS	Moderate Resolution Imaging Spectro-Radiometer
NASA	National Aeronautical and Space Administration
NASDA	National Space Development Agency of Japan
NIR	Near Infrared
NOAA	National Oceanographic and Atmospheric Administration
NPP	Net Primary Production
NSF	National Science Foundation
OLS	Optical Line Scanner
R&D	Research and Development
RID	Review Item Discrepancies
SAGE	Stratospheric Aerosol and Gas Experiment
SCF	Science Computing Facility
SMM	Solar Maximum Mission
SOLSTICE	Solar Stellar Irradiance Comparison Experiment
SPOT	Systeme pour l'Observation de la Terre
SSM/I	Special Sensor Microwave Imager
SSM/T	Special Sensor Microwave Temperature Sounder
SSM/IS	Special Sensor Microwave Imager and Sounder
SST	Sea Surface Temperatures
TDRSS	Tracking and Data Relay Satellite System
TES	Emission Spectrometer
TIR	Thermal Infrared
TIROS	Television Infrared Observing Satellite
TOMS	Total Ozone Mapping Spectrometer
TOPEX	Ocean Topography Experiment
TPFO	TOPEX/Poseidon Follow-On
UARS	Upper Atmosphere Research Satellite
USGCRP	US Global Change Research Program
UV	Ultraviolet
VNIR	Visible and Near Infrared
WCRP	World Climate Research Program
WOCE	World Ocean Circulation Experiment



EOS PAYLOAD ADVISORY PANEL MEETING

October 4-6, 1993

EOS Payload Advisory Panel

Instrument & IDS

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