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PAYLOAD ADVISORY PANEL RECOMMENDATIONS

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Easton, Maryland

Berrien Moore III, Chairman

Panel Members:

Mark Abbott
Eric Barron
John Bates (Richard Rood)
Getulio Batista
Peter Brewer
Josef Cihlar
Robert Dickinson
Jeff Dozier
William Grose
James Hansen (William Rossow)
Graham Harris (absent)
Dennis Hartmann
Bryan Isacks
Yann Kerr (absent)
William Lau
John LeMarshall (absent)
Timothy Liu (Mike Freilich)
Peter Mouginis-Mark
Masato Murakami (absent)
John Pyle (absent)
Jeffrey Richey
Franklin Robertson
Drew Rothrock
David Schimel
Mark Schoeberl
Piers Sellers
Rejean Simard
Soroosh Sorooshian (absent)
Meric Srokosz
Byron Tapley
Bruce Wielicki

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Payload Advisory Panel Recommendations

I. INTRODUCTION

The Payload Advisory Panel proposes a restructured Earth Observing System (EOS) mission to address high-priority science and environmental policy issues in Earth System Science. These issues have been identified through studies conducted by the Intergovernmental Panel on Climate Change (IPCC), the United States Environmental Protection Agency (EPA), and the Committee on Earth and Environmental Sciences (CEES). The restructured EOS defers efforts to improve the understanding of the middle and upper stratosphere and solid earth geophysics. The strategy of the mission combines high priority new measurements with continuation of critical data sets begun by missions which precede EOS. Collaborative arrangements with international partners are an essential part of the program and additional arrangements are proposed. The need for continuity in Earth observations and the urgency of environmental questions require launch of some EOS elements as soon as possible. They further require maintenance of the EOS objective of obtaining consistent 15-year measurement records.

The recommended complement of NASA-provided and/or -flown instruments is stated in Table 1. In Section II, we establish the context and prioritization for this payload recommendation (Table 2). The recommended implementation plan for the payload is presented in Section III (Tables 3 and 4). This plan sets forth a set of similar, moderate-sized platforms, a suite of Earth Probes and additional free flyers, and an *essential* dependence on international instruments and platforms for which definitive international commitments should be sought.

The Payload Advisory Panel's recommendation is to consider instrument groupings based upon scientific questions. These groupings combined with the Earth Probe and other free flyer payloads will study:

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

While this report focuses on the science program associated with instruments to be launched by NASA and international partners in the period 1997-2001 and beyond, EOS will build on progress from satellite missions that have now begun and will continue in the 1990s. It also provides a scenario for the 2001 - 2005 period. EOS will provide follow-on measurements to:

- Earth's radiation budget from ERBE and NIMBUS-7;
- Solar constant measurements from NIMBUS-7 and SMM;
- precipitation, snow and ice cover, and atmospheric water from the SSM/I on the DMSP series and the future TRMM mission;
- ocean color to be reinitiated by SeaWiFS;
- altimetric measurements begun by TOPEX/Poseidon;
- scatterometer observations to be reinitiated by NSCAT;
- land surface from Landsat, AVHRR, and SPOT programs;
- the operational meteorological satellites;
- stratospheric chemistry and dynamics from UARS and the Shuttle ATLAS mission;
- ozone from TOMS, SAGE II, and SBUV-2.

Although the proposed EOS program remains ambitious, it must be noted that it is considerably descoped from the original plan. While EOS will retain its emphasis on collecting observations over a 15-year period, many important measurements are cancelled, deferred, or proposed for provision by international partners. In many cases, EOS will now rely on domestic or international instruments that are less capable than those originally proposed. Some risk is associated with such reliance, and in some cases, continuity may be endangered. We have recognized these losses and risks, and we suggest strategies for mitigation.

Table 1 lists the instruments that are recommended for flight in the early and middle phases of the 15-year measurements from EOS missions. The square brackets [*] indicate a conditional on the recommendation. Table 2 links instruments to the science priorities. Tables 3 and 4 present the implementation plan. Additional issues are added as Comments to Tables 1, 3, and 4. Finally, the tables present the instruments in alphabetical order; Table 2 presents the scientific issues in priority order that is consistent with the IPCC findings.

Table 1. EOS Instrument Payload

Early Period (1997 - 2001)	Middle Period (Beyond 2001)	No Designated Launch date
U.S. Instruments		
ACRIM	ALT	LAWS
AIRS	GGI	
AMSU-A	GLRS-A	
CERES (7)	HIRIS	
[EOSP] (2)	[MLS or SAFIRE]	
HIRDLS (US/UK)	[MODIS-T]	
LIS (2)	TES	
MISR	FOLLOW-ON EARLY PAYLOADS	
MODIS-N (2)		
SAGE III (2)		
SOLSTICE		
Scatterometer		
SeaWiFS		
International Instruments		
ASTER (Japan)		
GLI (Japan)		
MHS (Eumetsat)		
MIMR (ESA)		
MOPITT (Canada)		
TOPEX/Poseidon-2 (France/US)		

Comments:

Early Period:
ACRIM, SOLSTICE - No orbital requirements other than solar viewing.
AIRS, AMSU-A, MHS - Synergistic package which must fly on the same platform, and desirable with MODIS-N and CERES.
CERES - One scanner on TRMM, two scanners each on the first and second EOS launch (AM and PM) and two scanners on the Japanese TRMM follow-on.
EOSP - Subject to a review by the Atmospheres Panel; one in polar orbit and one on a mid-inclination flight of opportunity.
HIRDLS - 50% UK contribution.
LIS - Flight on TRMM and on the Japanese TRMM follow-on.
MODIS-N - One instrument on each of the AM and PM launches.
SAGE III - One unit in sun-synchronous orbit, one in a mid-inclination flight of opportunity.
Scatterometer - Need for continuity of scatterometer data requires instrument with NSCAT-class accuracy and coverage.
SeaWiFS - Extended data purchase required for continuity until the launch of second MODIS-N.
TOPEX/Poseidon-2 (France/US) - Needed to avoid data gap.

Middle Period:
ALT - May need to be reviewed later in light of other oceanic altimeters.
MLS, SAFIRE - Future selection from descoped MLS and SAFIRE.
MODIS-T - Descoped version needed if GLI does not meet MODIS-T levels of performance for measurement of ocean biota.

No Designated Launch Date:
LAWS - Requires separate platform and adequate source of funding (international or domestic partner).
EOS SAR - Requires separate New Start and therefore not yet part of the EOS Payload.

II. THE CONTEXT FOR EOS

The programmatic context for EOS has changed since instruments were selected early in 1990 for the launch of the "EOS-A" satellite in 1998. The run-out budget through fiscal year 2000 was capped by the House-Senate Conference Report at $11 billion, down from approximately $17 billion. The Congress imposed a $44 million cut on the President's budget in FY 1991 and a $65 million cut in 1992, leaving an allocation for FY 1992 of $271 million. The Senate also indicated that the 1993 increment will be no more than $200 million, thus severely constraining the availability of funds in the near term.

The reduced funding profile for 1992-94 coupled with an overall $6 billion decrease in the budget for the first decade of EOS requires that we pursue only the highest-priority science and policy issues. The pursuit of these issues requires the U.S. to exploit fully the current operational satellites, U.S. Earth Probes and international space missions, and to employ a more phased implementation of the EOS program. This phasing is consistent with placing the EOS instrument configuration on moderate-sized platforms and associated smaller free flyers, as recommended by the EOS Engineering Review (EER) and subsequently as directed by the House-Senate Conference Report. Our recommended re-configuration leads to a flexible sequence of instruments and satellite payloads to implement the most important measurements, without delaying the launch of the first NASA satellite beyond 1998. The strategy can adapt to reordering of scientific priorities as our knowledge of the Earth improves. The lower budget, however, dictates increased reliance on our Japanese and European partners, through their programs that are associated with NASA's Earth Observing System, and on instruments furnished and operated by our domestic partners, National Oceanic and Atmospheric Administration (NOAA), the Department of Defense (DoD) and, potentially, the Department of Energy (DoE). It also relies upon new launch opportunities from the Western Test Range.

The revised set of instruments for the EOS satellites, operational satellites operated by NOAA and DoD, research missions during the 1990s such as UARS, SeaWiFS, TOPEX/Poseidon, TRMM, and instruments on Japanese and European platforms (e.g. ERS-1, ADEOS, POEM-1) will address many of the issues outlined in the reports of the IPCC, CEES, and EPA. To the findings in these reports, we have added our scientific judgement about emerging global change issues to design a focused program that remains scientifically robust, and thereby capable of addressing key issues that will face the world in the next three decades. The importance of maintaining a reasonable breadth is reinforced by the recent news from the 1991 International Scientific Ozone Assessment and studies indicating a "reverse greenhouse effect" associated with sulfate aerosols.

The scientific areas of importance and their linkage to the recommended instruments are outlined in Table 2 and discussed in more detail in the subsequent subsections.

Table 2. Science and Policy Priorities

Based on recommendations from the Intergovernmental Panel on Climate Change (IPCC), Committee on Earth and Environmental Science (CEES), and the US Environmental Protection Agency (EPA), we link EOS instruments in alphabetical order to the following categories listed in approximate priority order. Within each category, we identify only the most important instruments recommended for launch in the early EOS period (1997-2001). High-priority instruments recommended for launch after 2001 are enclosed in brackets. Consideration of EOS SAR was deferred.

Water and Energy Cycles:

- cloud formation, dissipation, and radiative properties, which influence response of atmosphere to greenhouse forcing;
- large-scale hydrology and moist processes, including precipitation and evaporation;
  - Instruments: AIRS/AMSU-A/MHS, CERES, [LAWS], MIMR, MISR, MODIS-N.

Oceans:

- exchange of energy and chemicals between ocean and atmosphere and between upper layers of ocean and deep ocean;
  - Instruments: ALT/GGI, MODIS-N, [MODIS-T/GLI], Scatterometer, SeaWiFs.

Chemistry of Troposphere and Lower Stratosphere:

- links to hydrologic cycle and ecosystems, transformation of greenhouse gases in atmosphere, and interactions with climatic change;
  - Instruments: HIRDLS, [MLS or SAFIRE], MOPITT, SAGE III, [TES].

Land Surface Hydrology and Ecosystem Processes:

- improved estimates of runoff over surface and into oceans;
- sources and sinks of greenhouse gases;
- exchange of moisture and energy between land surface and atmosphere;
  - Instruments: ASTER, [HIRIS], MIMR, MISR, MODIS-N.

Glaciers and Polar Ice Sheets:

- predictions of sea level and global water balance;
  - Instruments: ALT/GGI, ASTER, [GLRS-A], MODIS-N.

Chemistry of the Middle and Upper Stratosphere:

- chemical reactions, solar-atmosphere relations, and sources and sinks of radiatively important gases;
  - Instruments: EOSP, HIRDLS, [MLS or SAFIRE], SAGE III, SOLSTICE.

Solid Earth:

- volcanoes and their role in climate change;
  - Instruments: ASTER, [HIRIS], MISR, MODIS-N, SAGE III.

Water and Energy Cycles

The highest-priority science and policy issues revolve around potential changes in the Earth's water and energy cycles. Included are issues related to formation, dissipation, and radiative properties of clouds, which influence the response of the atmosphere to greenhouse forcing. Also critical is the need for improvement in understanding of global-scale hydrology and moist processes, including precipitation, snow cover, regional and global transport of water vapor, and evaporation from the land and ocean. The interactions between water vapor and radiation are one of the most important feedback processes in the atmosphere.

During the 1990s, we expect that experiments such as International Satellite Cloud Climatology Project (ISCCP), First ISLCP Field Experiment (FIRE), and Atmospheric Radiation Measurement (ARM) will improve our knowledge of cloud behavior; the Global Water and Energy Experiment (GEWEX) will address the large-scale hydrologic issues. The TRMM mission, in 1997, will start improved measurements of precipitation over regions where current data are inadequate but where remote sensing can provide adequate diurnal sampling. The TRMM mission, combined with the EOS instruments, will acquire crucial information on surface fluxes of water and the transport of water vapor through the atmosphere. Our knowledge of the role of aerosols in moderating greenhouse forcing will be improved by the French POLDER instrument on ADEOS. During the EOS period, MODIS-N, MISR, SAGE III, and EOSP, if selected, will provide more extensive information on aerosol formation, distribution, and diurnal variability.

The combination of CERES and MODIS-N will allow greatly improved quantification of the large-scale and low frequency variability of net incoming solar radiation and net outgoing long-wave radiation and their connection to cloud structure and coverage. This is fundamental to the study of the Earth's radiation balance and hence climate change as well as to improving the treatment of clouds in climate models. MISR, MODIS-N, SAGE III, and EOSP (if selected) will improve our understanding of the role of aerosols in the radiation balance. Understanding cloud formation processes and radiation interaction will be advanced by AIRS, AMSU-A, and MHS instruments which will determine the temperature with an accuracy of 1°K and water vapor profile up to the tropopause with an accuracy of 10% representing an improvement by a factor of three over the current radiosonde network with far greater spatial coverage. In addition, MODIS-N and MIMR sensors together will provide global mapping of snow cover in all weather conditions.

Oceans

The oceans transport significant quantities of energy and drive quasi-periodic, long-term changes in climate. Fluxes of energy, momentum, and fresh water between the atmosphere and the ocean surface affect ocean circulation and the availability of both water vapor and energy to the atmosphere. The exchange of CO_2 across the air-sea interface depends upon the difference of partial pressure and wind stress at the sea surface. Total dissolved inorganic carbon concentration, which is used to calculate the partial pressure in the sea surface, is controlled by ocean circulation and photosynthesis.

Early in the 1990's, the SeaWiFS data purchase will provide ocean color measurements, from which biomass and biological productivity can be estimated. TOPEX/Poseidon will measure ocean topography to improve our knowledge of the circulation of the upper ocean. The NASA Scatterometer (NSCAT) will fly on the Japanese ADEOS mission and will measure wind stress at the oceans' surface, as well as provide surface wind information for inclusion in models of the Earth's climate. Continuing observations of integrated atmospheric liquid water, water vapor, and surface wind speed from the Department of Defense (DoD) Special Sensor Microwave Imager (SSM/I) are being used to make estimates of monthly mean air-sea fluxes of heat and water. In addition, SSM/I observations of sea ice along with synthetic aperture radars on ERS-1, JERS-1, and Radarsat, are used in models of bottom-water formation and heat flux in the high-latitude oceans. NOAA's AVHRR provides high resolution sea surface temperature in cloud-free regions. Coupled with global field programs such as WOCE/TOGA and JGOFS, significant advances will be made in our understanding of the role of the ocean in the Earth system. However, as a result of the phasing of the satellite missions, large gaps in our knowledge will remain, especially in regards to linkages between physical and biological systems and between the ocean and atmosphere.

In 1998 and beyond, MODIS-N sensors flying in the morning and afternoon will continue the SeaWiFS measurements of ocean color and will improve the accuracy and resolution of sea-surface temperature measurements. Subsequently, more complete spectral measurements by sensors such as GLI (on ADEOS) or MODIS-T will allow separation of phytoplankton pigment into its critical components, thus significantly improving our understanding of ocean biogeochemical cycles. A NASA scatterometer flying on the Japanese ADEOS-2 mission or on an early EOS platform will continue the essential data set for ocean vector winds, allowing improved estimation of critical air-sea heat, momentum and chemical fluxes. AIRS/AMSU/MHS will provide accurate sea surface temperatures, as well as boundary layer temperature and moisture needed for monitoring air-sea energy exchange. Continuous time series of TOPEX/Poseidon-class altimetric measurements will allow the study of critical components of low frequency variability of basin-scale ocean circulation. The European multi-frequency microwave radiometer (MIMR) will provide information about sea ice and atmospheric water content at a higher spatial resolution than SSM/I, and the added 6 GHz channel will allow all-weather estimation of sea surface temperature under cloud cover. Finally, either in the EOS suite of instruments or via an international partner, it will be important to continue with ocean topography measurements.

Chemistry of Troposphere and Lower Stratosphere

The critical issues associated with the chemistry of the troposphere and lower stratosphere are understanding the transformation of trace and greenhouse gases within the troposphere, the changes in the oxidizing capacity of the troposphere through anthropogenic processes, the exchanges of gases between the troposphere and stratosphere, the radiative impact of ozone changes, and the role of heterogeneous chemical processes within the lower stratosphere.

In this decade, the Upper Atmosphere Research Satellite (UARS) will improve knowledge of the coupling of radiative, dynamic and chemical processes within the middle and upper stratosphere. Less will be learned about the chemistry of the lower stratosphere from UARS; however, aircraft campaigns during the next decade will contribute to our knowledge of lower stratospheric and tropospheric chemistry. These campaigns will focus on specific trace gas transport and transformation mechanisms, but will not provide needed global surveys of tropospheric constituents such as ozone, ozone precursors, and other biogeochemically important trace gases.

In the EOS era, we will investigate the interaction and evolution of tropospheric trace and greenhouse gases with the climate and biosphere using TES and MOPITT. The combination of measurements provided by SAGE III, HIRDLS and MLS or SAFIRE will provide continuity in the stratospheric O_3, water vapor and temperature data record. These instruments, along with TES, will allow us to address questions of stratospheric-tropospheric exchange, changes in upper tropospheric ozone and water vapor (key greenhouse gases), and changes in the chemistry of the lower stratosphere including the role of heterogeneous processes.

Land Surface Hydrology and Ecosystem Processes

Improved estimates of water and energy fluxes between the atmosphere and the land surface, and of runoff over the land surface and into oceans, are needed to determine the exchange of moisture and energy between the land surface and the atmosphere, which is needed for realistic climate simulations. In addition, regional precipitation is controlled, in part, by terrestrial processes including the biota. Finally, the land biota also act as both sources and sinks of carbon dioxide and other important greenhouse gases.

In this decade, programs such as the International Satellite Land Surface Climatology Project (ISLSCP) and GEWEX will examine exchanges of water, energy, and chemicals between the surface and the atmosphere. The Landsat archive and continuing series will be used to examine historical changes in land cover, land use, and the distribution of biomass. The Panel is encouraged by the introduction of recent legislation to make Landsat data more available to global change researchers. Until the launch of EOS, AVHRR will be the only source of data for global-scale monitoring of vegetation dynamics on phenological and sub-seasonal time scales, which is essential for the study of the exchanges of water, energy, and carbon between the land and the atmosphere. Synthetic aperture radars flying on European, Japanese, and Canadian satellites will monitor deforestation and surface hydrology.

After 1998, the EOS instruments, particularly MODIS-N and MISR, will enable global mapping of the surface vegetation for models of exchange of trace gases, water, and energy with the atmosphere. ASTER will provide simultaneous multi-spectral, high resolution detail to support this mapping. The ability, with MISR, to correct land surface images for changing atmospheric conditions and sun-sensor geometry will qualitatively increase our ability to monitor and quantify changes in the activity of the land biosphere. In the longer term, HIRIS is expected to monitor changes in vegetation chemistry closely coupled to carbon storage. The passive microwave radiometer MIMR, with finer spatial resolution than SSM/I, will allow improved mapping of snow cover and snow water equivalent in all weather conditions, along with vegetation moisture. When implemented, the EOS multi-frequency SAR will enable global studies of structural vegetation characteristics such as biomass, along with soil moisture and snow properties. The ability of SAR to penetrate cloud cover and dense plant canopies make it particularly valuable in rain forest studies.

Glaciers and Polar Ice Sheets

Predictions of sea level change depend directly on estimates of the mass balance of the ice on the Earth's land surfaces. Changes in the mass balance of glaciers and ice sheets are also time-integrated indicators of climate change. Currently our data are inadequate to assess whether the Antarctic and Greenland ice sheets are growing or shrinking.

In the pre-EOS time-frame, radar altimeter data from Seasat and GEOSAT are not available for Antarctica, and are only available for Greenland to latitude 72°N. Surface measurements of mass balance are sparse, hence the uncertainty in our knowledge of the state of the second largest reservoir of water, after the oceans.

The GLRS-A laser altimeter is the key instrument for starting mass balance measurements of polar ice sheets; it will fly in the middle EOS era (2001-2005). ASTER will map glacier features and thereby provide data from which glacier flow rates can be measured. MODIS-N will provide the broad patterns of areal extent and coverage.

Chemistry of the Middle and Upper Stratosphere

The middle and upper stratosphere is the region of ozone formation. Rapid anthropogenic chemical changes are occurring in this region. Associated with the changes are ozone loss and possible cooling of the middle and upper stratosphere. This ozone loss will increase the UV flux into the lower atmosphere.

UARS, along with the NOAA SBUV-2 and the Shuttle ATLAS missions, are examining and will continue to examine the chemical and dynamical processes of the middle and upper stratosphere, the mesosphere, and lower thermosphere, including high altitude solar-atmospheric effects during the first part of the 1990's. SAGE II continues to provide high precision ozone, water, and aerosol measurements. Complementing the space-borne measurements will be the ground-based Network for Detection of Stratospheric Change (NDSC).

Starting with the first EOS instrument launches, HIRDLS and SAGE III will continue monitoring the middle and upper stratosphere. SAGE III will continue and improve the high precision ozone, water and aerosol record begun by SAGE I and SAGE II, while HIRDLS provides high spatial resolution daily global mapping of temperature, ozone, water, methane, CFCs, and other important trace gas species. The later launch of either MLS or SAFIRE will complete the minimum required trace gas measurement set with observations of hydroxyl and halogen oxide radicals. The EOS instrument measurements will be augmented by a suite of ESA stratospheric instruments proposed for POEM-1 and the continued expansion of NDSC, which permits the significant descoping of the payload for this area.

Solid Earth

Solid Earth processes are important to climate change, particularly in their interactions with the hydrologic cycle and ecosystems, and more directly through input of particulates and aerosols by volcanic eruptions and wind erosion.

Currently, remote sensing data are used mainly to investigate geologic structure and identify broad groups of surface minerals. Data from Landsat, SPOT, and the Shuttle Imaging Radar experiment have contributed data to these studies.

The primary instrument package for surface imaging (ASTER, MODIS-N, and MISR) will contribute to studies of volcanic processes, soils, erosion, glacial movement, changes in land use, desertification, topography, land surface emissivity, and temperature. ASTER, MISR, and EOSP will examine volcanic plumes and aerosols, and SAGE III will give additional information on aerosols reaching the upper troposphere and lower stratosphere.

III. IMPLEMENTATION

The implementation of the EOS measurement suite must build on the investment made in Earth observations in the 1990s and provide additional capability for observing critical Earth system processes. Tables 3 and 4 summarize the Panel's recommendations both in terms of NASA-flown payloads and NASA-provided instruments for flights on international partner spacecraft or free flyers. Synergistic instrument clusters have been identified that attack specific scientific problems (e.g., cloud feedbacks). To the extent that instrument clusters *can* be accommodated on the same spacecraft, errors owing to temporal variability in observed phenomena are minimized.

We recognize that NASA has made preliminary agreements with international partners for instrument exchanges. In several instances, the payload we recommend *requires* revisions or extensions of these agreements. We *strongly urge* NASA to explore such revisions, because we believe they greatly increase the scientific potential of the overall international Earth Observing System.

In constructing payloads to address the key EOS science issues outlined in Section II, we have assessed technical and fiscal feasibility given platform and budgetary constraints. We also have considered impacts on the size and implementation schedule of EOSDIS. Where instrument clusters did not need to fly on the same spacecraft, we have considered relative launch dates of NASA and international partner platforms. Throughout, we have attempted to minimize science risks that would result from programmatic disruptions or delays.

The recommended NASA morning platform includes a powerful suite of sensors (CERES, MODIS-N, and MISR) focussed on cloud and aerosol radiative properties. Measurement of the diurnal properties of clouds and radiative fluxes requires measurements on the NASA am and pm sun-synchronous orbits as well as the TRMM inclined orbit. Another cluster on the NASA morning platform (MODIS-N, MISR, and ASTER) will address issues related to air-land exchanges of energy, carbon, and water, a task that is only qualitatively addressed by AVHRR now. MOPITT, SAGE-III, and HIRDLS provide critical data related to tropospheric and lower stratospheric chemistry and dynamics, including troposphere-stratosphere exchanges.

The instruments on the recommended NASA afternoon platform allow study of cloud formation, precipitation, and radiative properties. A subset of these instruments (AIRS/AMSU-A/MHS, MIMR, and MODIS-N), in concert with vector wind stress measurements from NSCAT-2 (on ADEOS-2), are required for studies of air-sea fluxes of energy and moisture. MIMR, MODIS-N, and AIRS contribute greatly to studies of sea-ice extent and heat exchange with the atmosphere. Flight of this platform during the operational lifetime of TRMM would allow definitive assessment of the utility and accuracy of precipitation estimates based on MIMR data. MODIS-N and MIMR will allow mapping of snow water equivalent and the monitoring of variability and change with respect to the climate and hydrological system.

The measurements of the external solar forcing of the Earth System will be provided by ACRIM and SOLSTICE; however, they need not fly on any specific platform or in any particular orbit, other than sun-viewing. CERES and LIS in an inclined orbit will improve the diurnal coverage and could be implemented by the TRMM-2. EOSP and SAGE III in an inclined orbit will similarly improver coverage and for SAGE III there is the needed improvement in observing polar regions.

Variations in ocean absorption of solar radiation caused by changes in bio-optical properties can be investigated using yet another set of instruments (MODIS-N and GLI, with SeaWiFS-2 providing continuity of ocean color measurements until both MODIS-N instruments are flying). More importantly, this cluster (along with vector winds from NSCAT-2) will allow estimation of ocean-atmosphere exchanges of carbon with significantly improved accuracy.

The recommended NASA-supported or -flown EOS initial suite consists of 20 instruments on approximately seven platforms to be launched in the 1997-2001 time frame (Table 3). Investigation of key IPCC priority areas and continuation of crucial time series (first established in the early 1990s) will be carried out using both intra- and inter-platform instrument groupings. The listing within clusters is alphabetical.

The recommended payload scenario (given in Table 4) for the years 2001 - 2005 and beyond focuses upon implementing altimetric, ice sheet, and tropospheric chemistry instruments on various free flyers, and reflying the basic clusters from the early AM and PM platforms. Listings are alphabetical.

Table 3. Recommended Instruments and Clusters for 1997 - 2001

NASA AM Cluster	NASA PM Cluster	Japan ADEOS-2	Free Flyers
ASTER	AIRS	GLI (MODIS-T)	SeaWiFS-2
CERES (2)	AMSU-A	NSCAT-2	TOPEX/Poseidon-2
MISR	CERES (2)		TRMM-2
MODIS-N	MHS		
	MIMR		
	MODIS-N		
Polar Orbit of Opportunity	**Inclined Orbit of Opportunity**	**Other Orbit of Opportunity**	
[EOSP]	CERES	ACRIM	
HIRDLS	[EOSP]	SOLSTICE	
MOPITT	LIS		
SAGE III	SAGE III		

Comments:

[EOSP] - Pending report from Atmosphere Panel.

GLI (MODIS-T) - Descoped version of MODIS-T needed if GLI does not meet MODIS-T level of performance for measurement of ocean biota.

HIRDLS, MOPITT, SAGE III - Subset should be considered for NASA AM Cluster.

NSCAT-2 - Must be considered for the PM Platform (STIKSCAT) or Polar Orbit of Opportunity if not accommodated on ADEOS-2.

SeaWiFS-2,TOPEX/Poseidon-2, TRMM-2 - Needed for data continuity; would require new Earth Probe and/or foreign partnership.

Table 4. Recommended Instruments and Clusters for the Early 21st Century

NASA Missions	NASA AM Clusters	NASA PM Clusters	Free Flyers
ALT	CERES	[AIRS]	LAWS
GLRS-A	[EOSP]	AMSU-A	TRMM-3
GGI	HIRIS	CERES	
MLS or SAFIRE	MISR	[MHS]	**Flights of Opportunity**
TES	MODIS-N	MIMR	ACRIM
	SAGE III	MODIS-N	[EOSP]
		[MODIS-T]	HIRDLS
		[STIKSCAT]	SAGE III (mid-inclination)
			SOLSTICE

Comments:

AIRS and MHS - Recommended to migrate to NOAA operational platform hence listed in brackets.

ALT,GLRS-A, and GGI - Form a potential grouping.

EOS SAR - Requires New Start, and consideration by the Panel was deferred at this time..

[EOSP] - Pending report from Atmospheres Panel.

HIRDLS - Possible migration to NOAA.

MODIS-T - Listed in brackets indicating possible flight as GLI.

STIKSCAT - Listed in brackets indicating possible continued flight on Japanese ADEOS series.

TES and MLS or SAFIRE - Could be on a free flyer.

TRMM-3 - Would require new Earth Probe and/or foreign partnership.

Implementation Issues for the Early EOS Period

Scatterometry

Continuity of all-weather wind stress measurements with those initiated on ADEOS (1995) requires early flight of an NSCAT-class scatterometer. The recommended baseline scenario does not have a scatterometer on either NASA platform. Early flight of a scatterometer and continuity of the data set is important and it can be achieved through flight of an NSCAT copy on the Japanese ADEOS-2 mission (1998 or 1999 launch). If NSCAT-2 cannot be accommodated on ADEOS-2, the flight of STIKSCAT on the NASA afternoon platform has high scientific priority and we recommend that STIKSCAT be added to the NASA PM payload. If simple addition to the payload cannot be accommodated, deferral of another instrument must be considered. However, because of the scientific cohesion of the other instruments on the afternoon platform, this would be a difficult choice and would require re-examination by the Payload Advisory Panel. This hypothetical situation would present a clear conflict between continuity of a key measurement and disruption of a well-justified synergistic instrument cluster. Continued flight by ESA of an AMI-type scatterometer does not meet the EOS measurements requirements.

Ocean Color

Initially, only one MODIS-N will be available for the collection of ocean color information. The flight of SeaWiFS-2 in 1997 would not only overlap with SeaWiFS-1 (providing critical cross-calibration data), but it will provide continuity of the ocean color data set until the second MODIS-N becomes available. Such limited-band information (MODIS-N and SeaWiFS) will allow studies of ocean biomass and primary productivity, but full spectral data will eventually be required in order to separate the classes of phytoplankton present in the upper ocean on a global scale. Such information is critical to understand the carbon cycle of the ocean and its response to climate change. Thus we recommend a strong scientific and technical collaboration between the MODIS-T effort at NASA and the Japanese GLI activity. This joint study should focus on developing a Japanese ocean color spectrometer that will meet the scientific requirements defined for MODIS-T. If this is not feasible, then we strongly recommend that a redefined MODIS-T (designed only for ocean color observations) fly on the second copy of the NASA afternoon payload, or on a near-noon, sun-synchronous flight of opportunity in the middle EOS time period.

High-Resolution Land Imagery

The optical sensors for the global study of the land surface (MODIS-N, MISR) are designed to be used in conjunction with the Landsat Thematic Mapper (TM). Sub-seasonal global coverage is required to track biological and other changes that are below the spatial resolution of these systems. ASTER and later HIRIS will provide some data for this purpose, but their swath widths are inadequate to acquire sub-seasonal coverage. Thus it is imperative that the Landsat TM capability be preserved in the EOS era.

Altimetry

A long-time series of altimetric measurements of the ocean will be established by DoD, ESA, NASA and CNES. The Panel rates continuity of these measurements as important. To this end, altimeters are planned to be flown on POEM-1 (ESA), GEOSAT follow-on (DoD), and possibly on ADEOS-2 (NASDA). While these missions will provide valuable data early in the EOS era, we recommend a TOPEX/Poseidon-class mission between 1997-2001 to continue studies of global ocean circulation that are crucial to the Earth's energy balance. Such a mission would fill the gap until the EOS Altimeter launch after 2001. Because of constrained budgets, NASA may need to enter into a partnership to provide these essential altimetric measurements.

Clouds and Radiation

The panel has three main recommendations concerning measurements of cloud physical properties and understanding their effects on the radiation budget of the earth-atmosphere system.

First, it is highly desirable to move the CERES scanner from the ESA POEM-1 platform onto the NASA AM platform. The primary reason for this shift is the large improvement in measuring cloud physical properties using the MODIS-N spectrometer as opposed to the NOAA VIRSR cloud imager on ESA's POEM-1. We recognize, however, that this action may affect accommodation and early flight of HIRDLS, SAGE III, or MOPITT. If the accommodation issues cannot be resolved, then the CERES scanner should remain on the ESA POEM-1 platform.

Second, we recognize that the accuracy of CERES radiative fluxes is limited by time sampling and angular sampling errors. For time sampling, we recommend flight on two sun synchronous orbits (NASA AM and PM platforms), and one mid-inclined orbit (TRMM and TRMM follow-on), all flying in the same epoch. The initial TRMM will be flown with only one CERES scanner; however, for angle sampling, we recommend the flight of two CERES scanners with MODIS-N, for co-located cloud physical properties measurements, on the two initial polar platforms and two on the Japanese TRMM follow-on. Later, re-flights can reduce to a single CERES scanner.

Third, there is a substantial risk of a large gap between 1990 and 1997 in radiation budget data derived using broadband scanning radiometers. A part of this gap (1994-1996) may be filled using the French-Soviet ScaRaB instrument. NASA should aid, as appropriate, the accurate ground calibration of ScaRaB in an ERBE-class calibration facility. NASA should also evaluate cooperation with DoE on possible provision of ERBE-class scanner for radiation budget data in the 1995-1997 time-frame. It is noted that all three ERBE non-scanning instruments continue to acquire data, but these data are far less useful for climate studies that the scanner data.

Aerosols

Tropospheric and lower stratospheric aerosols may have a critical role in moderating the effect of greenhouse forcing. The Panel places a high priority on aerosol measurements including information on their formation, distribution, and diurnal variability. Three instruments that measure important properties are MODIS-N, MISR, and EOSP. The Panel recommends coincident flights of MODIS-N, MISR, and EOSP (pending further evaluation by the Atmospheres Panel) to provide maximum aerosol information from the same air mass. In addition, the Panel may recommend the flight of EOSP in a mid-inclination orbit to study the diurnal variability of aerosols using polarimetry. The Payload Advisory Panel has requested that the Atmospheres Panel convene a special study team to evaluate the contribution of EOSP in light of the recommended payload and focus for EOS. This team should report by January 1, 1992.

Tropospheric and Lower Stratospheric Chemistry

MOPITT, HIRDLS, and SAGE III are critical instruments for the measurement of change in atmospheric composition related to the atmospheric transformation of greenhouse gases, and all three should fly early in the program. One copy of SAGE III should be flown in a mid-inclination orbit (See next subsection, Platforms of Opportunity); a second copy is needed in polar orbit.

There is considerable flexibility in the flight accommodation of these instruments. SAGE III could fly alone and is easy to accommodate with other instruments. HIRDLS can also fly alone or on virtually any of the polar spacecraft. MOPITT requires flight with either MODIS-N/AIRS or an operational sounder. These instruments could fly on the first EOS platform, but this may lead to accommodation problems. This problem may be solved by seeking accommodation on international partner platforms or dedicated free-flyers, where appropriate. These accommodation issues are referred to the Program Office, which should bear in mind the high priority the Panel attributes to these instruments. The Panel notes that HIRDLS and MOPITT are synergistic for studies of upper tropospheric chemistry, and that formation flying or co-location is preferred, but is secondary to early flight.

Platforms of Opportunity

The Panel continues to recommend SAGE III on a medium-inclination (approx. 57 degrees) orbit, in addition to a polar orbit, to continue the ozone, water vapor, and volcanic aerosol measurement continuity with earlier SAM and SAGE data. The Panel also notes that ACRIM and SOLSTICE could be flown on a separate sun pointing platform. Further efforts to identify flight opportunities are needed.

Climsat

Instruments currently proposed for Climsat and the need for a Climsat mission should be scientifically reviewed and considered in light of the instruments recommended for the EOS payload, the TRMM mission, and other Earth observing missions by ESA and Japan. The measurements that Climsat is to make are included within the Panel's recommendations for EOS.

Platform Focus and Instrument Clusters: Middle EOS Period

The payload scenario for the years 2001-2005 and beyond (Table 4), following the initial flights of the EOS and international partner spacecraft, involves flight of altimetric, ice sheet, and tropospheric chemistry instruments and re-flights of the earlier NASA morning and afternoon missions with modified instrument complements.

Land Spectrometric Issues

HIRIS is proposed to replace ASTER on re-flight of the AM platform and to continue on subsequent flights. The deferred flight of HIRIS allows sufficient time for investigation of HIRIS technology with special attention to the continued development of the focal plane. While HIRIS holds considerable potential for analysis of terrestrial biogeochemical cycles, key questions remain. The HIRIS team should be directed to address with definitive studies 1) the ability of the instrument to measure remotely plant chemical attributes controlling rates of decomposition, and 2) a global observing strategy that will allow the monitoring of changes in plant tissue chemistry that are predicted to occur in response to climate change and CO_2 enrichment. In order to accomplish these goals, it is critical that provision be made for the timely acquisition of data required to address the questions above. While HIRIS lacks the thermal infrared channels of ASTER (and so is not a direct replacement), it is needed to measure changes in terrestrial biogeochemistry, a key indicator of changing carbon storage as temperature and carbon dioxide concentration change. Reflight requirements for the thermal infrared spectrometer of ASTER should be studied along with the HIRIS questions.

Scatterometry Issues

Continuity of the scatterometer surface wind data series must be maintained throughout the EOS era. In the post-2001 period, several options may exist for flight of NSCAT-class scatterometer instruments: re-flight of NSCAT-3 on a NASDA ADEOS-3 platform; re-flight of STIKSCAT on the NASA afternoon platform follow-on; and flight by ESA of an advanced scatterometer (ASCATT) on the ESA POEM-2 platform. Specific choice of option depends upon the results of early-EOS accommodation studies and upon analysis of the utility and accuracy of the ESA system.

LAWS

LAWS wind data are viewed by the Payload Panel as extremely important for characterizing the three-dimensional tropospheric wind field, calculation of transports of moisture and trace gases, and developing a cloud climatology especially in the southern hemispheres and over oceans. The LAWS instrument, as currently configured, requires both a separate platform and additional funding for implementation. To this end, the Panel strongly encourages NASA to develop interagency and international partnerships involving the existing LAWS team.

EOS SAR

EOS SAR capability is required to measure globally biomass, soil moisture, and polar ice dynamics. The proposed EOS SAR instrument has been descoped to provide the minimum capability to measure key parameters in ecosystem dynamics, hydrology, solid earth and cryospheric science. Some EOS needs will be met by Japan's JERS-1, ESA's ERS-1 AMI and follow-on instruments, and Canada's Radarsat. As with LAWS, the Panel encourages NASA to develop interagency and international partnerships to design and build a multi-frequency, multi-polarization SAR that will address the new, broader science objectives within the context of the IPCC/CEES priorities.

Upper and Middle Stratospheric Chemistry

The chemistry of the middle and upper stratosphere will continue to be monitored by HIRDLS, SAGE III, and SAFIRE or MLS. SAFIRE and MLS are currently undergoing descope activities relative to lower stratospheric and upper tropospheric measurements. One of the two instruments will be recommended for flight in the middle EOS time period following additional consideration by the Atmospheres Panel.

The EOS instruments SWIRLS, XIE, GOS, and IPEI were selected for EOS for their ability to address solar-atmospheric physics and upper atmospheric processes. Because these issues are no longer considered high priority for the EOS mission and given budget constraints, the Panel does not recommend continuation of these instruments.

Interactions with NOAA

Continuing data series from the NOAA operational meteorological satellites, both polar and geostationary, are necessary to address emerging global change issues. NOAA has expressed an interest in operational deployment of AIRS, HIRDLS, CERES, ALT, STIKSCAT, MIMR, and LAWS. The payload implementation schedule assumes that AIRS and HIRDLS will be continued by NOAA after their initial flights. NOAA is actively studying flights of AIRS, CERES, and HIRDLS after the first EOS payload. Given the possibility that these instruments will appear on the second EOS launch in 2000, the timing of transition will require further interaction with NOAA counterparts. In summary, the likelihood and timing of instrument transfer to NOAA needs clarification, and consideration must be made about the possible impact of continuation of these instruments as part of EOS.

Interactions with DoE

The ARM and Remotely Piloted Aircraft (RPA) programs proposed by DoE are of special significance when combined with the global space-based measurements of EOS. Development of advanced technologies by the DoE may be of special value to global change issues. Those technologies associated with improved synthetic aperture radars and improved lasers for Doppler lidar direct measurement of winds, precise ice-sheet altimeter, and potentially space-borne water vapor lidar measurements are especially important. These technology improvements should be incorporated into the appropriate instruments as they are demonstrated to be able to contribute to global change measurements. As recommended by the EOS Engineering Review Committee, it is worthwhile that DoE use its resources to provide early (by 1995) contributing measurements to the observation of long-term Earth radiation budget variability. This is particularly important given the uncertainties associated with the ScaRaB mission.

Interactions with DoD

Continuing data series from some operational satellites of DoD are necessary to address emerging global change issues. In the case of DoD, issues that must be addressed, particularly with respect to SSM/I include -- through and into the EOS time-frame -- continued data archiving including ready -access by the scientific community; improved arrangements on determining data needs and access so the system can be relied on by the scientific community; and continued efforts to provide an accurate geo-located output, which can be integrated with other data sets. DoD plans for enhanced operational sensors -- up to and into the EOS time-frame -- and how they might contribute to the EOS mission should be determined. It is particularly important to continue the SSM/I program to provide a continuous passive microwave data series, which started in 1978 with SMMR. Closer interaction between NASA and DoD could also occur if the National Land Remote Sensing Policy Act of 1991 is implemented.

IV. SUMMARY

We have identified a scenario for flights of NASA EOS platforms and instruments that assures continuity of important climate measurement time series, addresses high priority science and policy issues identified by the IPCC, and is consistent with technical, budgetary, and schedule constraints. While the program as proposed will provide a significant advance in our understanding of climate processes and change, it is neither sufficiently extensive to solve all identified climate problems nor is its implementation without some risk.

Cost savings result from the following changes in implementation. First, a reduction in the number of instruments and changes in launch schedules have affected both the size and development pace of EOSDIS. Second, several instruments (described below) have been eliminated from the program. Third, some instruments have been deferred until later in the mission, thus reducing the number of instrument copies. Similarly, some instruments should transition to the operational NOAA series. Fourth, increased reliance has been placed on international partners for critical measurements, again reducing the number of NASA-provided instruments or instrument copies or platforms.

What has been lost:

The removal of middle stratospheric wind and particle and field (SWIRLS, XIE, GOS, IPEI) instruments and the cancellation of either MLS (descoped) or SAFIRE (descoped) will result in the loss of ability to completely characterize the stratosphere during a period of rapid anthropogenic chemical change.

The deferral of sensors that collect complete spectral information (visible spectral coverage by MODIS-T and HIRIS, shortwave infrared coverage by HIRIS, and thermal infrared interferometry by TES) will reduce our ability to study the exchange of trace gases between the ocean, land, and atmosphere, and increases in the near-term the chance that unanticipated environmental events will be missed.

Descoping of GLRS to remove laser ranging capability (GLRS-R), as the result of the adoption of the IPCC priorities, has reduced our ability to characterize solid earth processes that precede and follow earthquakes and volcanic eruptions. This capability should be pursued through development in other NASA programs, as well as with the collaboration with other agencies or international partners.

Determination of whether the polar ice sheets are growing or shrinking is deferred until after 2000. Changes in ice sheet volume are critical indicators of multi-year climate change. Monitoring ice sheets is needed to understand and predict sea level change.

What is at risk:

Continuity of data is at risk: scatterometer data if NSCAT-2 is not carried on ADEOS-2; continuity of ocean color data without extension of SeaWiFS purchase; continuity of ocean topography data without TOPEX/Poseidon follow-on; long data gap in ERBE-quality radiation budget measurements if ScaRaB (France/USSR) or DOE instruments are not available before the launch of TRMM, and continuity of precise ozone profile measurements without flight of SAGE III on satellites in mid-inclination orbits.

The implementation strategy is at risk if key EOS sensors do not migrate to operational agencies, such as NOAA. Global measurements of the tropospheric wind field and the determination of the transport of moisture and trace gases are a risk without the flight of LAWS. Finally, we have not been able to identify flights of opportunity for solar irradiance measurements made by ACRIM and SOLSTICE and therefore important solar forcing terms are at risk.

Role of the Payload Advisory Panel

The Payload Advisory Panel's current recommendations include statements of payload implementation options and proposed international collaborations. It is not the intention of the Payload Advisory Panel that it be consulted on every decision. Instead, the Panel has tried to provide a scientific rationale that underlies our recommendations, to define flexible instrument clusters, and to recommend alternate measurement and accommodation strategies. The Payload Advisory Panel should be consulted in the event that a) significant instrument, platform, or launch capability issues arise, b) substantial new funding constraints appear, or c) we are unable to achieve the recommended international accommodations. The Panel is particularly concerned about flight of MOPITT, SAGE III, and HIRDLS in this century. We remain available to review NASA's plans at periodic opportunities.