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Responding to directions from the EOS Engineering Review Committee, Congress, and the EOS Payload Advisory Panel, NASA has announced plans for the restructured Earth Observing System (EOS). The restructured program will address high-priority science and environmental policy issues in Earth system science, and will fly instruments on intermediate-sized and smaller spacecraft, instead of a series of large platforms. It will have more resilience and flexibility, allow adjustment to smaller levels of funding expected from Congress, and take advantage of new launch opportunities for the EOS spacecraft, particularly the expected availability of Atlas IIAS launch vehicles from the West Coast.

Although the restructured EOS program remains ambitious, it is reduced from the original plan proposed in 1990, with its EOS-A satellite to be launched in 1998 and EOS-B in 2001. The reduction is required by the restricted funding levels placed on NASA by Congress and the White House:

- a Congressional reduction in the fiscal year 1992 budget from $336 million to $271 million;
- a President's 1993 budget of $390 million;
- a cap on the integrated budget through fiscal year 2000 of $11 billion, down from the originally proposed $17 billion.

THANKS, STAN. WELCOME, GHASSEM.

Stan Wilson, the EOS Program Scientist, has left NASA to become the Assistant Administrator at NOAA/NOS, 1825 Connecticut Ave. N.W., Suite 611, Washington, D.C. 20235. Ghassem Asrar has become the new EOS Program Scientist.

We are grateful to Stan for guiding EOS during its turbulent early days, through the selection process for instruments and investigators, through the initial platform configuration and schedule, and finally through the restructuring brought on by a smaller budget. He also kept his eye on our long-term concerns, setting up smaller workshops between interdisciplinary investigators and instrument team members to make sure that the scientific measurements from the instruments meet the needs of the broader science community. We wish Stan well in his new position, and expect to see him frequently as we try to merge the needs of the scientists served by both agencies.

Many of us know Ghassem Asrar from the First ISLSCP Field Experiment (FIFE). He was at Kansas State University when the FIFE investigators began working at the nearby Konza Prairie Long-Term Ecological Reserve, and he was thus called on to help many of us while he was also involved in his own investigations. At NASA Headquarters, he has managed the hydrology program and led the selection process for the NASA Global Change Fellowships, while continuing to publish his own work on remote sensing. He brings to the position a broad understanding of large-scale hydrologic problems and a commitment to the full spectrum of Earth System Science.

The reduced funding requires that NASA pursue only the highest priority science and policy issues. EOS will retain its emphasis on collecting observations over a 15-year period, but many important measurements are cancelled, deferred, or proposed for provision by international partners. For many measurements, EOS will now rely on international or domestic instruments that are less capable than those originally selected. Some risk is associated with such reliance, and continuity of some important data sets may be endangered. The suite of scientific problems addressed by EOS is also narrowed. Of the global change issues that could be studied, the one perceived to most need improved scientific understanding for policy decisions is global climate change. Accordingly, the restructured EOS will emphasize studies of global climate change, and will make only limited observations of stratospheric chemistry and solid Earth geophysics.

SCIENTIFIC FOCUS OF EOS

The Payload Panel defined the following science and policy priorities, as selected by the EOS Payload Advisory Panel, based on recommendations from the Intergovernmental Panel on Climate Change (IPCC), the Environmental Protection Agency, and the Committee on Earth and Environmental Sciences.

a. 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

b. Oceans
  - exchange of energy, water, and chemicals between ocean and atmosphere and between upper layers of ocean and deep ocean (includes sea ice and formation of bottom water)

c. Chemistry of Troposphere and Lower Stratosphere
  - links to hydrologic cycle and ecosystems, transformations of greenhouse gases in atmosphere, and interactions with climatic change

d. 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
  - changes in land cover

e. Glaciers and Polar Ice Sheets
  - predictions of sea level and global water balance

f. Chemistry of the Middle and Upper Stratosphere
  - chemical reactions, solar-atmosphere relations, and sources and sinks of radiatively important gases

g. Solid Earth
  - volcanoes and their role in climatic change

Accordingly, the selected instruments for EOS 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.

Omitted from the planned instruments are measurements of the middle and upper stratosphere and those associated with solid-Earth geophysics.

EOS will build on progress from satellite missions that have now begun and will continue in the 1990s. EOS will provide follow-on measurements to:

- Earth's radiation budget from ERBE (Earth Radiation Budget Experiment) and Nimbus-7;
- precipitation, snow and ice cover, and atmospheric water from TRMM and SSM/I, part of DMSP
- ocean color from SeaWiFS, which continues measurements begun by CZCS;
- altimetric measurements begun by TOPEX/Poseidon;
- scatterometer observations from NSCAT, to fly on the Japanese ADEOS;
- land surface measurements from Landsat, AVHRR, and SPOT programs;
- operational meteorological satellites;
- stratospheric chemistry and dynamics from UARS;
- ozone from TOMS and SAGE II.

EOS INSTRUMENT CONFIGURATION

Selected Instruments

The EOS instruments that NASA plans to fly in the "Early" EOS period (1997-2000) and beyond are summarized in the sections that follow. These instruments combine high-priority new measurements with continuation of critical data sets begun by missions that precede EOS. The need for continuity in Earth observations and the urgency of environmental questions require launch of some EOS elements as soon as possible, collaborative arrangements with international partners, and maintenance of consistent 15-year records.

EOS Instruments in Early Period (1997-2000)

(Details about instruments may be found in the 1991 EOS Reference Handbook.)

AIRS, AMSU-A, and MHS
Atmospheric Infrared Sounder, Advanced Microwave Sounding Unit-A, and Microwave Humidity Sounder; team leader M. T. Chahine, Jet Propulsion Laboratory; a synergistic package that will provide temperature and humidity sounding with much better accuracy than current sensors.

ASTER
Advanced Spaceborne Thermal Emission and Reflection Radiometer; H. Tsu, Geological Survey of Japan; high-resolution images of land surface, water, and clouds from visible through thermal infrared wavelengths; one stereophotogrammetric band.

CERES
Cloud and Earth's Radiant Energy System; B. R. Barkstrom, NASA Langley Research Center; on multiple satellites in morning, afternoon, and inclined orbit to measure Earth's radiation balance.

MIMR
Multifrequency Imaging Microwave Radiometer; European Space Agency; precipitation, cloud water, sea surface temperature and roughness, snow and ice extent, snow water equivalence, soil moisture.

MISR
Multi-angle Imaging Spectro-Radiometer; D. J. Diner, Jet Propulsion Laboratory; global maps of planetary and surface albedo, aerosols, and vegetation properties.

MODIS-N
Moderate-Resolution Imaging Spectrometer - Nadir; V. V. Salomonson, NASA Goddard Space Flight Center; in both morning and afternoon orbits; comprehensive, global geophysical and biological processes.

MOPITT
Measurements of Pollution in the Troposphere; J. R. Drummond, University of Toronto; carbon monoxide and methane.

SAGE III
Stratospheric Aerosol and Gas Experiment III; M. P. McCormick, NASA Langley Research Center; global profiles of aerosols, clouds, temperature, and pressure in stratosphere.

SeaWiFS
Sea-Viewing Wide Field-of-View Sensor; NASA; ocean color and productivity; continuation of 1993 mission.

Other EOS Instruments Beyond 2000

ACRIM
Active Cavity Radiometer Irradiance Monitor; R. Willson, Jet Propulsion Laboratory; exoatmospheric solar irradiance.

ALT
Altimeter; L.-L. Fu, Jet Propulsion Laboratory; dual-frequency radar altimeter for sea-surface topography.

EOSP
Earth Observing Scanning Polarimeter; L. D. Travis, NASA Goddard Institute for Space Studies; globally maps radiance and linear polarization of reflected sunlight to measure aerosol characteristics.

GGI
GPS Geoscience Instrument; W. Melbourne, Jet Propulsion Laboratory; tracks GPS (global positioning system) satellites for precise positioning information, global geodesy, atmospheric temperatures, and gravity waves.

GLRS-A
Geoscience Laser Ranging System - Altimeter; B. Schutz, University of Texas; topography of glaciers and ice sheets, cloud heights, and droplet sizes.

HIRDLS
High-Resolution Dynamics Limb Sounder; J. Barnett, Oxford University, and J. Gille, National Center for Atmospheric Research; global measurements of temperatures, water vapor, and chemical species in upper troposphere and stratosphere.

HIRIS
High-Resolution Imaging Spectrometer; A. F. H. Goetz, University of Colorado; images of Earth with high spectral and spatial resolution for vegetation properties, mineral identification, characteristics of inland waters, oceans, snow, and clouds.

SOLSTICE
Solar Stellar Irradiance Comparison Experiment; G. J. Rottman, University of Colorado; ultraviolet solar irradiance.

STIKSCAT
Stick Scatterometer; M. H. Freilich, Jet Propulsion Laboratory; wind vectors and stress at sea surface.

TES
Tropospheric Emission Spectrometer; R. Beer, Jet Propulsion Laboratory; global, three-dimensional profiles of virtually all infrared-active gases from surface to lower stratosphere.

Instruments Still Under Consideration

Either MLS or SAFIRE will be selected for flight on an as-yet unidentified mission.

MLS
Microwave Limb Sounder; J. Waters, Jet Propulsion Laboratory; atmospheric gases important in ozone destruction, especially chlorine and nitrogen species.

SAFIRE
Spectroscopy of the Atmosphere Using Far Infrared Emission; J. M. Russell III, NASA Langley Research Center; chemical, radiative, and dynamical processes that influence ozone changes.

Instruments Deselected from the EOS Program

Instruments deselected from EOS because of the reduction in funding are:

GLRS-R
Geodynamics Laser Ranging System - Ranging; B. Schutz, University of Texas; geodynamics portion of the GLRS instrument; measurements of crustal motion, geological processes and features.

GOS

Geomagnetic Observing System; R. Langel III, NASA Goddard Space Flight Center; Earth's magnetic field, for studies of core fluid dynamics and mantle conductivity.

IPEI

Ionospheric Plasma and Electrodynamics Instrument; R. Heelis, University of Texas; thermal ion and electron temperatures, ion composition, and ion dynamics in ionosphere.

LIS

Lightning Imaging Sensor; H. Christian, NASA Marshall Space Flight Center; distribution and variability of lightning; will fly on Tropical Rainfall Measuring Mission (TRMM).

MODIS-T

Moderate-Resolution Imaging Spectrometer - Tilt; V. V. Salomonson, NASA Goddard Space Flight Center; ocean primary productivity and biogeochemistry, bidirectional reflectance of land surface.

SWIRLS

Stratospheric Wind Infrared Limb Sounder; D. J. McCleese, Jet Propulsion Laboratory; structure, dynamics, and transport in stratosphere.

XIE

X-Ray Imaging Experiment; G. K. Parks, University of Washington; total particulate energy precipitated into Earth's atmosphere.

EOS Instruments Not Yet Funded

EOS instruments for which funding is not yet identified are:

LAWS

Laser Atmospheric Wind Sounder; W. E. Baker, NOAA National Meteorological Center; tropospheric winds, aerosols, and cirrus clouds.

SAR

Synthetic Aperture Radar; C. Elachi, Jet Propulsion Laboratory; three-frequency radar for deforestation, soil and canopy moisture, snow accumulation and wetness, sea ice properties.

Implementation

The table below summarizes the schedule for launch of the EOS instruments. The implementation of the EOS measurement suite builds on the investment made in Earth observations in the 1990s and provides additional capability for observing critical Earth system processes.

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 caused by temporal variability in observed phenomena are minimized. In constructing payloads to address the key EOS science issues, NASA assessed technical and fiscal feasibility, given constraints imposed by budgets and size of launch vehicles.

SCHEDULE FOR DEPLOYMENT OF EOS INSTRUMENTS

Observatory	Date	Orbit	Launch Vehicle Class	Instruments
AM-1	1998	polar	Atlas IIAS	ASTER CERES MISR MODIS-N MOPITT
SeaWiFS II	1998	polar	Pegasus	SeaWiFs
Aerosol-1	2000	57 deg	Pegasus	SAGE III
PM-1	2000	polar	Atlas IIAS	AIRS AMSU-A CERES MHS MIMR MODIS-N
Altimetry	2002	polar	Delta II	ALT GGI GLRS-A
Chemistry	2002	polar	Atlas IIAS	HIRDLS SAGE III STIKSCAT TES
AM-2	2003	polar	Atlas IIAS	CERES EOSP HIRIS MISR MODIS-N
Aerosol-2	2003	57 deg	Pegasus	SAGE III
PM-2	2005	polar	Atlas IIAS	AMSU-A MODIS-N CERES MIMR AIRS/MHS (or substitute)

The recommended NASA morning platform includes a suite of sensors (CERES, MODIS-N, and MISR) focused on cloud and aerosol radiative properties.

Measurement of the diurnal properties of clouds and radiative fluxes requires measurements on the AM-1 and PM-1 sun-synchronous orbits as well as the inclined orbits provided by the Tropical Rainfall Measuring Mission (TRMM) and the Aerosol observatories. Another cluster on the AM-1 spacecraft (MODIS-N, MISR, and ASTER) will address issues related to air-land exchanges of energy, carbon, and water, a task that is addressed now only qualitatively by AVHRR. For imaging of the land surface, a morning crossing time improves the probability of image acquisition because clouds are less frequent then.

The instruments on the recommended NASA afternoon platform allow study of cloud formation, precipitation, and radiative properties. A subset of these instruments (MIMR, AIRS/AMSU-A/MHS, and MODIS-N), in concert with vector wind stress measurements from a scatterometer (recommended for consideration for Japan's ADEOS-II), are needed for global-scale studies of air-sea fluxes of energy and moisture. MIMR, MODIS-N, and AIRS contribute to studies of sea-ice extent and heat exchange with the atmosphere. Flight of this platform during the operational lifetime of TRMM will allow 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 of the climate and hydrological systems.

The morning observatory (AM-1) is scheduled to launch before PM-1 because: (i) it will yield important measurements of both clouds and radiation and surface characteristics; and (ii) it is more straightforward to execute than the PM-1 observatory. The AM-1 spacecraft includes only one challenging U.S.-furnished instrument: MODIS-N, whereas the PM-1 includes both MODIS-N and the AIRS instruments. Thus, the cost and schedule for AM-1 are less demanding than for PM-1.

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. NASA is examining flight opportunities for these instruments. CERES and LIS in an inclined orbit on TRMM will improve diurnal coverage and could be implemented on a follow-on TRMM in the next century. SAGE III in an inclined orbit will similarly improve coverage.

Variations in ocean absorption of solar radiation caused by changes in bio-optical properties can be investigated with SeaWiFS-II providing continuity of ocean color measurements until both MODIS-N instruments are flying. Along with vector winds from a scatterometer, these measurements will allow more accurate estimates of ocean-atmosphere exchanges of carbon.

The Altimetry spacecraft provides two altimeters: ALT and GLRS-A. ALT is a dual-frequency radar altimeter for accurate measurements of ocean-surface topography, from which circulation is inferred. GLRS-A is a laser altimeter for accurate profiles, which are particularly needed to establish the changes in volume of the ice sheets in Greenland and Antarctica. GGI enables the precise positioning of the spacecraft needed to interpret altitude measurements from either instrument, and it also allows for sparse but extremely accurate temperature profiles of the upper atmosphere.

HIRDLS, SAGE III, and TES on the Chemistry observatory, along with MOPITT on AM-1 and SAGE III on the Aerosol spacecraft, provide critical data related to tropospheric and lower stratospheric chemistry and dynamics, including troposphere-stratosphere exchanges. STIKSCAT measures the wind stress and vector winds at the ocean surface, so that air-sea exchanges can be estimated.

EOS is a long-term program, providing continuous observations of the causes of global climate change. The planned payload scenarios for the years beyond 2003 thus focus on reflying, at least twice, the the basic clusters from the AM-1 and PM-1 spacecraft, at five-year intervals. However, the payloads on the follow-on EOS spacecraft will change as scientific understanding of global change evolves and technology improves. The Payload Panel recommended that the HIRIS instrument supplement or replace ASTER on AM-2. AIRS and MHS may move to the NOAA operational spacecraft. Decisions about instruments to fly on follow-on spacecraft need not be made for a few years, but technology development efforts need to continue to make sure that such next-generation instruments are available when needed.

Deviations from the Payload Panel's Recommendations

The instruments and launch sequences that NASA has planned follow closely the recommendations of the Payload Advisory Panel, with a few deviations or exceptions.

The Payload Panel recommended that HIRDLS and STIKSCAT (or another scatterometer) fly before 2001. In NASA's scenario HIRDLS and STIKSCAT will fly in 2002. The NASA Scatterometer (NSCAT) will fly on Japan's ADEOS mission in 1995, but there will be a discontinuity of scatterometer data from 1999-2002. NASA will examine the possibility of flying either HIRDLS or a second NSCAT on Japan's ADEOS-II mission in 1999.

The Payload Panel recommended a polar flight of opportunity for SAGE III. NASA is investigating the possibility of flying SAGE III on the first European polar platform in 1998.

The Payload Panel recommended a flight for MODIS-T in the next century, but this instrument has been deselected. They also recommended follow-on missions to TOPEX/Poseidon (an ocean altimeter to be launched in 1992) and TRMM (1997).

The Payload Panel emphasized the importance of both LAWS and SAR for studies of global change. Both are expensive, technologically challenging instruments; NASA will need help from other domestic agencies (such as the Departments of Energy or Defense) or international partners. Especially welcome would be more compact, cheaper versions.

SUMMARY

The selected EOS instruments and spacecraft assure continuity of important time series of climate measurements, address high-priority science and policy issues identified by the IPCC, and are consistent with technical, budgetary, and schedule constraints. The instruments, configurations, and launch schedule have been selected after extensive debate and discussion among the investigators. It is now time to get on with the mission. ❒

Jeff Dozier
EOS Project Scientist

ANNOUNCEMENT

NASA Graduate Student Fellowships in Global Change Research.

NASA announces graduate student training fellowships for persons pursuing a Ph.D. degree in aspects of global change research. These fellowships will be available for the 1992/1993 academic year. The purpose is to ensure a continued supply of high-quality scientists to support rapid growth in the study of Earth as a system. A total of 96 fellowships have been awarded since the inception of the program in 1990. Up to 45 new fellowships will be awarded in 1992, subject to availability of funds.

Applications will be considered for research on climate and hydrologic systems (including tropical precipitation), ecological systems and dynamics, biogeochemical dynamics, solid Earth processes, human interactions, solar influences, and data and information systems. Atmospheric chemistry and physics, ocean biology and physics, ecosystem dynamics, hydrology, cryospheric processes, geology, and geophysics are all acceptable areas of research, provided that the specific research topic is relevant to NASA's global change research efforts, including the Earth Observing System, the Tropical Rainfall Measuring Mission, and Mission to Planet Earth. THE DEADLINE FOR SUBMITTING APPLICATIONS IS APRIL 1, 1992.

For further information contact Dr. Ghassem Asrar, NASA Headquarters, (202)453-8195.

Atmospheres Panel

Contributors:

D. Hartmann (Chairperson)
M. Schoeberl
M. Prather
A. Roche
D. Buhl

Measurements of Atmospheric Composition in the Lower Stratosphere: Essential Contributions of MLS and SAFIRE-II

I. Prologue

On December 19, 1991 the Atmospheres Panel held a special meeting at the Goddard Space Flight Center to consider the key role of the SAFIRE and MLS instruments in providing measurements of atmospheric composition in the lower stratosphere and upper troposphere. This report reviews again the reasons why these measurements will be needed to address current and anticipated global change priorities, and provides a recommended prioritization of the measurement capabilities of these two instruments. Approximately 40 people attended all or part of the meeting during which the instruments and their capabilities were discussed. A smaller group of people with no direct connection with either of the instrument teams met after the general meeting to discuss whether a clear recommendation could be made regarding which of these instruments should be given a higher scientific priority.

In making these recommendations we are assuming that SAGE-III, HIRDLS and TES will be flown and consider only the augmentation that MLS and SAFIRE will provide to EOS measurement capability, with particular emphasis on the lower stratosphere.

It should be noted that both instrument designs are evolving with time, and they retain some flexibility to measure slightly different constituent sets than were presented at the meeting. Both teams presented designs that were reduced in cost, weight, data rate and power requirements from their original proposals, and were focused on a minimal set of key measurements. Both teams reported that they could produce additional measurements at modest cost, but presented only what they had confirmed they could do within the designs proposed. It is these key measurements that we have used for our intercomparison, although we will also mention in passing the additional measurements that the respective teams have suggested should be attainable with additional effort.

II. Background

In the August Seattle Investigators Working Group (IWG) meeting, the IWG was presented with revised EOS goals in response to budgetary constraints. The revised EOS goals were based upon the IPCC/CEES global change priorities. As translated into EOS measurement priorities, less emphasis is now placed on the upper stratospheric measurements and more emphasis on lower stratospheric measurements. In response to this shift in priority, the IWG asked the various Panels to make recommendations concerning instrument selection to the Payload Panel.

Prior to the Seattle IWG, the Atmospheres Panel had been examining the atmospheric trace gas measurements and instruments proposed by EOS, ESA and other programs and agencies in relation to duplication of capability, normal advances in scientific understanding, and resiliency of proposed instruments. The Atmospheres Panel recommended a strategy of trace gas monitoring for EOS. That strategy consists of the measurement of key source gases, key reservoir species, basic physical properties of the stratosphere (temperature, aerosols and UV flux), and a key radical from each of the main families (O_x, ClO_x, NO_x, HO_x). The key trace gases are listed in Table 1. The Panel also noted that the EOS instruments for measuring stratospheric composition are more advanced and more capable than instruments proposed to fly on ESA or Japanese platforms. The Panel strongly recommended the flight of SAGE III, HIRDLS, MLS and/or SAFIRE for chemical measurements. SAGE III was recommended mainly for its high accuracy ozone profile measurements and its aerosol trend detection abilities, although it is also capable of measuring H_2O, NO_2 and $OClO$. The spatial and temporal sampling of SAGE III is limited to those times and places where the instrument can view the sun through the limb of the atmosphere, however. HIRDLS was recommended for its high horizontal resolution global mapping capability and its measurement of source gases, ozone, temperature, and NO_x.

Even with HIRDLS and SAGE III, however, it is clear from Table 1 that a large number of key components of stratospheric chemistry will not be measured if MLS and SAFIRE are not flown. Furthermore, none of the MLS/SAFIRE - unique trace gas measurements will be made by non-EOS satellite instruments, and no other experiments possess the critical capability provided by MLS and SAFIRE to make accurate chemical constituent measurements in the presence of substantial amounts of stratospheric aerosols.

With the reduction in the EOS budget, it has become clear that NASA may not receive enough funds to develop and launch both MLS and SAFIRE. Following its October 21-24 meeting, the Payload Panel asked the Atmospheres Panel to evaluate the merits of these instruments and recommend a priority. Both instrument PI's had begun rescope activities to focus their instruments more narrowly toward IPCC/CEES priorities and the suite of key trace gases that the Atmospheres Panel identified as most critical.

Table 1: EOS Lower Stratospheric Chemistry
(Instrument Capabilities as of December 19, 1991)

Key Measurements	Instrument(s)
1. Long Term O_3	SAGE III> HIRDLS, MLS, SAFIRE
2. Global Mapping O_3	HIRDLS>MLS, SAFIRE
3. Global Mapping T	HIRDLS>MLS, SAFIRE
4. Radicals	
OH	SAFIRE, MLS
$C1O$	MLS
NO_2	HIRDLS, SAGE III
(NO_3)	SAGE III
($OC1O$)	SAGE III
(BrO)	MLS*
(NO)	MLS*
(HO_2)	SAFIRE>MLS*
5. Reservoirs	
HC1	MLS, SAFIRE
HF	MLS
($C1ONO_2$)	HIRDLS
(HNO_3)	HIRDLS, MLS, SAFIRE
(H_2O_2)	SAFIRE
(HOC1)	SAFIRE>MLS*
(HBr)	SAFIRE
(N_2O_5)	HIRDLS, SAFIRE
6. Source Gases	
H_2O	HIRDLS>SAGE III, MLS, SAFIRE
N_2O	HIRDLS, MLS
CH_4	HIRDLS
CFC's	HIRDLS
7. Other Physical Processes	
Aerosols/PSC's	SAGE III
UV Flux	Solstice II

Key:
() Indicates additional useful trace gas not included in the original Atmosphere Panel list.
* Indicates zonal averages only, below 30km, not individual profile measurements

A>B, C means instrument A is preferred over B or C usually because of greater number of measurements, higher precision, or the capability to make individual profile measurements as opposed to zonal means. The ability of MLS and SAFIRE to measure some constituents in the presence of heavy aerosol loading is not reflected in the table.

III. Contributions to Stratospheric Chemistry Monitoring

As described above, the need for MLS/SAFIRE capability with EOS has been argued in the Atmospheres Panel Report to the Payload Panel. The "Seattle Payload" (SAGE III & HIRDLS) would measure the long-term changes in the stratosphere and upper troposphere of O_3, T, H_2O and some of the source gases (CH_4, N_2O, CFC's). The Atmospheres Panel believes that it is necessary to document changes in the quasi-conserved families (NOy, Cly, Bry) and to observe the global distributions of reservoir species (HCl, HF, HNO_3, $ClONO_2$) and key radicals in these families and in the odd-hydrogen system (e.g., OH, HO_2, ClO, BrO, NO_2). The augmentation of the "Seattle Payload" with these measurements is essential if we are to understand any possible changes in ozone and to ascribe cause and effect. SAFIRE and MLS are the only instruments that can measure many of the necessary reservoir and radical species. (The measurements of HNO_3 and $ClONO_2$ on HIRDLS are important, but not adequate in themselves to understand the cause of potential shifts in lower stratospheric chemistry.)

The new MLS instrument (de-scoped version) meets the requirements set forth by the Atmospheres Panel for minimal global monitoring of lower stratospheric chemistry. It can measure the OH and ClO radicals into the lower stratosphere. Further, it monitors the important reservoir species HCl, HF (unique) and HNO_3 (redundant with HIRDLS, except in the presence of a thick aerosol layer). In addition, MLS as currently presented would extend the radical observations to other families by giving monthly zonal-mean observations of BrO, HO_2, and HOCl, and daily zonal mean measurements of NO. A capability of MLS (and SAFIRE also) that sets it apart from the Seattle Payload is its ability to continue to observe O_3, T, H_2O and HNO_3 in the lower stratosphere in the event of significant volcanic activity and aerosol loading for which conditions HIRDLS would be ineffective. If this were to happen in the early part of the 21st century with the highest levels of stratospheric chlorine experienced to date, we must be able to continue to monitor the expected ozone depletion and the other chemical changes associated with the ozone decline. MLS also offers the unique capability of simultaneously monitoring O_3 and N_2O (a quasi-conservative tracer) under such circumstances, thus allowing us to separate ozone loss from transport in the lower stratosphere. Another feature of MLS observations of volcanic clouds is the ability to monitor SO_2 and OH simultaneously, thus measuring the key process of oxidizing SO_2 into H_2SO_4.

The SAFIRE-II instrument (de-scoped version) meets most of the minimum requirements. It can measure the OH and HO_2 radicals into the lower stratosphere. Further, it monitors the important reservoir species HCl, HBr, HNO_3, and N_2O_5. HNO_3 and N_2O_5 are also measured by HIRDLS, but SAFIRE would provide measurements when heavy or spatially patchy aerosol loading is present. In addition, SAFIRE gives us profiles of HO_2, H_2O_2, and HOCl to extend the observations of the HOx and Cly families. SAFIRE would provide individual profile measurements of all the constituents in its repertoire. A capability of SAFIRE that sets it apart from the Seattle Payload is its ability to continue to observe O_3, T, H_2O, HDO, HNO_3 and N_2O_5 in the lower stratosphere in the event of significant volcanic activity and aerosol loading similar to MLS capability (see above). A unique capability of SAFIRE is its ability to measure the H_2O/HDO ratio, which is useful for studying stratosphere/troposphere exchange.

Some uncertainty remains about the comparative precision of the OH measurements that would be obtained from MLS and SAFIRE in the lower stratosphere. The information was not presented in exactly the same form by both instrument teams. The SAFIRE team presented retrieval simulations, and the MLS team presented a signal-to-noise analysis. The relative accuracy of the two OH measurements was not agreed upon by the two teams. We do not believe that the probable differences between the OH capabilities of these two instruments, if any, would have a decisive influence on our recommendations.

Both teams also suggested that they could probably make additional measurements that were not included in their presentations, but that they would need to do additional work to confirm this. The SAFIRE team felt that they could measure $CLONO_2$ in the far IR, which would extend the HIRDLS measurements of this constituent into conditions with a heavy aerosol burden. The MLS team felt that they might be able to produce single profile measurements of HO_2 and HOCl, if they worked on the problem. Both teams had focused their efforts on those constituents that the Panel had identified as the critical minimum list.

IV. Technology and Risk

Both MLS and SAFIRE are state-of-the-art instrument designs. To determine whether technological risk was an important factor, the Panel asked Drs. David Buhl and Aidan Roche to attend the meeting and evaluate these issues. The primary concerns focused on the lifetime of the cooling system for SAFIRE and the development of a space-qualified CO_2 pump laser for the 118 micron receiver required for the OH measurement on MLS. These experts agreed that the technology proposed for these instruments is well within the bounds of what could reliably be done prior to a post-2000 launch, and that technological risk was not a critical factor for either instrument.

The advertised capabilities of both instruments were discussed extensively, including the measurement strategy. It was generally agreed that both teams had fairly represented their instruments and presented realistic estimates of instrument capabilities.

V. Recommendations

1. Every effort should be made to develop both MLS and SAFIRE for flight early in the next decade. Both SAFIRE and MLS provide measurements of key source gases, reservoir species and radicals from the important oxygen, nitrogen, hydrogen, chlorine, and bromine families in the lower stratosphere. Because of their use of relatively long wavelength radiation, most of these measurements can be obtained even in the presence of substantial stratospheric aerosol abundances or thin clouds in the upper troposphere. These instruments would allow monitoring of stratospheric chemistry both inside and outside stratospheric aerosol clouds. Critical molecules for which these instruments provide unique measurements include OH, HO_2, HCl, HOCl, ClO, BrO, CH_3Cl, and HF. SAFIRE plus MLS would also provide additional measurements of O_3, H_2O, N_2O, HNO_3, N_2O_5, SO_2, CO, and NO, which are key species measured by other instruments proposed for flight as part of EOS (i.e., SAGE III, HIRDLS, TES), but they would provide these measurements in the presence of heavy stratospheric aerosol loading, through which the other EOS instruments cannot obtain constituent measurements. Each instrument has unique capabilities, and the ability to fly both simultaneously would clearly enhance the scientific return of EOS and our understanding of changes in the stratosphere.

2. If sufficient funds to develop both of these instruments cannot be secured, we believe that MLS should be given a higher priority for development than SAFIRE. The decisive scientific reason for this recommendation is the ability of MLS to monitor ClO in the lower stratosphere, which is directly involved in the rate-limiting reactions for the catalytic destruction of ozone by chlorine.

3. The Panel was very impressed by the thought and effort that both instrument teams put into descoping and focusing their instruments. In view of the fiscal constraints facing the EOS project, and the reduced size of the platforms, the Panel believes that it would be very valuable for every instrument team to undertake such a critical reappraisal, if they have not done so. ❐

Solid Earth Panel

B. L. Isacks, Chairman
Peter Mouginis-Mark
with contributions from Panel members

Introduction

The Solid Earth Panel of the Earth Observing System (EOS) Investigators Working Group (IWG) prepared`this document in response to the consideration of scientific priorities for EOS that took place during the late summer and fall of 1991, at the Seattle meeting of the IWG and the Easton meeting of the Payload Advisory Panel. The discussions at those meetings centered on the research priorities set forth in the IPCC assessment of climate change (Houghton, et al., 1990). This report thus focuses on the importance of solid Earth science to those issues of climate change and does not consider a number of important areas where satellite remote sensing plays critical roles in understanding the solid Earth component of the Earth system. These areas, well summarized in the Coolfont Report (NASA, 1991), include studies of the Earth's geopotential fields, tectonic plate motions, Earth strains related to large destructive earthquakes and other lithospheric and mantle processes, and lithospheric structure and evolution. Within these constraints, the report thus focuses on the dynamic interactions of the solid Earth and climate as manifested primarily in the terrestrial land surface system and by the effects of volcanos on climate.

The report first argues for a higher priority for the terrestrial land surface system than seems to be given in the IPCC document, at least as this document was interpreted at the EOS meetings during the fall of 1991. The report then discusses the critical roles of solid Earth science in the integration of disciplines that will be necessary to fully cope with the complexity of the land surface system.

Land Surface System as a High Priority for EOS Science

As the abode of our species, the terrestrial land surface system clearly should be the most critical part of the Earth system to observe and understand. Human beings live on the land surface, have affected it the most, and therefore give it the most concern. However, the extreme degree of heterogeneity and complexity of the land surface demand patient and careful observation with monitoring at scales ranging from local to continental over a sufficient span of time scales to reveal the full range of states of the system. The history of the system is therefore important. The local and regional scales are critical, not just to parameterize better sub-grid processes in global scale models, but to understand how the system actually works at the human scale.

However, unlike the oceans and the atmosphere, study of the very complex land surface system has become fragmented into diverse disciplines spreading across academic and applied arenas, including biology, hydrology, soil science, environmental science, geology, geography, and climatology. This fragmentation is well summarized by the recent National Academy of Sciences report of the Committee on Opportunities in the Hydrologic Sciences (1991) and is exemplified by the scattering of pieces of the land surface system into four different panels of the EOS Investigators Working Group (Land Biosphere, Biogeochemical Cycles, Physical Climate and Hydrology, and Solid Earth). EOS is likely to have a revolutionary impact on the study of the land surface system, not only because of the unprecedented range of spatial scales and monitoring possibilities provided by the satellite observations of the Earth, but because it will force the integration of disciplines and the development of the new cross-disciplinary studies that are required to understand the human habitat.

The Solid Earth Panel thus supports the view that the land surface system, broadly conceived to include the interactions of the terrestrial biosphere, hydrosphere, lithosphere, and atmosphere, should be among the highest priorities in EOS science.

Solid Earth Science and IPCC Priorities

Land Surface System

Besides providing the long-term perspective on Earth structure and evolution, solid Earth science plays major roles in the interactions of the litho-sphere, atmosphere, hydrosphere, and biosphere that constitute the land surface system. The roles involve soil, rock, groundwater, topography, and crustal structure, and the processes of volcanism, crustal deformation, weathering, transport, and deposition of crustal materials. Interactions of the solid Earth with the atmosphere and biosphere occur over an enormous range of time scales that extend from short-term processes relevant to human activities to long-term evolutionary changes over geological eras. Closely coupled interactions between solid Earth processes and climate, e.g., tectonic-topographic-climate feedbacks via orographic effects on circulation and changing fluxes of CO_2 related to weathering of silicate rocks are important features of the Earth system, but are generally assumed to occur over time scales substantially longer than those of concern to human activities. At the relevant time scales of decades to centuries, interactions of the atmosphere and solid Earth feature the occurrences of large "events": volcanic eruptions, earthquakes, large storm-triggered erosional (fluvial or aeolian) episodes, and glacial surges which have significant impacts on climate or the land surface system on regional and global scales.

Large volcanic eruptions affect the chemistry and radiative properties of the atmosphere globally and deposit ash over large areas of the land surface with sudden but drastic effects on the hydrosphere and biosphere, and little known but probably important effects on oceans. Earthquakes change the elevations of certain coastal regions by up to 10-20 meters and thereby affect the interactions of ocean, land, and climate in those areas. Earthquake shaking, in concert with climatically and topographically controlled increases in ground instability, can lead to large and often highly destructive mass movements that profoundly affect the regional hydrological regimes, contribute the most important component of the erosional mass flux, and may permanently alter the landscape. Similarly, large mass fluxes may be associated with severe storms. The role of relatively rare but large storms or other meteorological extrema on the hydrological regime of a region is a closely related problem. Climatically driven changes in soil moisture and vegetation can lead to very large changes in erosion rates, as can the land use practices of human societies. Aridity and high winds can combine to inject large quantities of particulates into the atmosphere with important consequences to regional and global climate.

These phenomena illustrate how inextricably solid Earth processes are a part of a unified science of terrestrial hydrology and land surface processes. They are also an inextricable part of concerns about the impacts of climate change on human societies. Examples of these concerns include water quality and supply; topsoil erosion; siltification of reservoirs and estuaries; vunerability to earthquake, volcanic, or storm-related mass movements; and tsunami, earthquake, or storm-related changes in coastlines in relation to rising sea level. Studies of these fast- acting, interactive solid Earth phenomena are an important contribution to EOS objectives, whether those objectives are development of an all embracing Earth system science or a narrower focus on prediction of climate change relevant to development of adaptation and mitigation policies for the terrestrial habitat of human societies.

Volcanism

Eruptions of volcanoes such as Mount Pinatubo in June, 1991, can inject millions of tons of ash, gases, and aerosols into the upper troposphere and lower stratosphere over a time scale of a week to several months. Assessing the impact of these eruptions on the Earth system requires both the estimation of the rate at which solid and gaseous material are erupted (i.e., the volume, temperature, velocity-field, and height distribution of these materials) and the measurement of the nature and recovery time of the transient disturbances to the atmosphere, land surface, and/or sea surface. Particularly in the case of volcanogenic material injected into the stratosphere, it is the rate of conversion of sulfur dioxide to sulphate aerosols and the residence time of the aerosols in the stratosphere which are responsible for the duration of the regional or hemispheric cooling due to volcanic eruptions. The direct and indirect effects of eruptions on a wide range of biomes, particularly alpine or boreal biomes which are already under stress, can last for months to decades.

While explosive eruptions are more spectacular than volcanic activity that produces lava flows and volcanic domes, the contribution of gases released into the atmosphere from surface activity may also have significant impact on the Earth system. Because of the greater solubility of sulfur in basaltic magmas compared to more silicic magmas, eruptions of volcanoes such as those found in Iceland can inject more than an order of magnitude more sulfur into the atmosphere than an eruption of an equivalent volume of silicic magma. The 1783 eruption of Laki in Iceland is a case in point, where the eruption of large volumes of basalt over a period of seven months resulted in a volcanic fog that affected the weather in northern Europe for a couple of years.

Climate History

The importance of climate history to the evaluation of future climate change is emphasized in the IPCC document. One of the key problems is the understanding of natural climate variability, which may include rapid transitions, surprises, in the highly non-linear Earth system that are difficult if not impossible to predict. Study of past climate change offers the only perspective on what the Earth system has actually done. This is an area where solid Earth science has had the major role. The record of past climate is preserved in the sedimentary (including ice) records on land and the ocean bottom and in outstanding characteristics of the terrestrial landscape. On land the stratigraphic data are sampled by isolated and sparsely distributed point locations where cores are taken, and the results must be interpreted in respect to the spatially variable terrestrial climate system. The sparse spatial sampling thus makes interpretations in terms of global climate changes difficult.

The landscape itself, however, records the spatial pattern of an extremely important episode of climate history, one that is most relevant to the study of modern climate change. This episode is the transition from full glacial to our present inter-glacial global climate system during the past 20,000 years. The last glacial cycle has left striking imprints on vast areas of the terrestrial landscape and had profound impacts on the hydrosphere and biosphere. All considerations of the modern state and changes of the land surface system need to have this perspective.

Evidences of climate regimes quite different from the present are recorded in spatial detail across vast regions in the form of glacial moraines, cirques, and periglacial features indicative of past distributions of snow and ice; stabilized sand dunes, wind-carved landscape features and other indicators of past wind velocities; relict lake shores, alluvial fans, fluvial systems buried beneath sand, river valley morphologies not in equilibrium with the modern hydrological regime, and other terrain features indicative of past precipitation/evaporation regimes.

Although Quaternary geologists have long studied instances of paleoclimatic features at local scales on the ground, the enormous potential of satellite observations for this work has not yet been realized. The imprints of late Quaternary climate and hydrological changes on the landscape can be very effectively studied on regional to continental scales by satellite observations. Besides identification and mapping of features, determinations of ages and chronologies can be made with combinations of satellite measurements of reflected and emitted spectra and radar roughness and field sampling at key localities.

To interpret the spatial information on past climate we need to understand the spatial variability of present terrestrial climate. This requires the advanced capabilities of EOS to characterize the spatial and temporal variability of modern climate and hydrology on regional to continental scales. One of the primary uncertainties in the interpretation of climate chronologies at isolated points is the large spatial variability of terrestrial climate, particularly in mountainous regions. A better characterization of modern climate is required to interpret past climate change in terms of the complex spatial variability of the terrestrial system.

This task is closely related to mainstream objectives of EOS in the areas of 4-D assimilation and mesoscale climate modeling to predict future climate and hydrological changes at scales relevant to the complex variability of climate over land. Combining studies of modern and past climates provides a valuable historical perspective to the development of adaptation and mitigation policies in respect to future climate change. The study of past variability shows what types of change have occurred and how these changes are manifested in the terrestrial hydrological system.

Satellite Geodesy: Changing Sea Level, Ice Volumes, Earthquakes, and Earth Rotation

Sea level rise from a combination of increased water temperature and melting of ice is one of the pressing concerns discussed in the IPCC document. This is a multi-faceted problem requiring significant input from oceanography, climatology, hydrology, and solid Earth science. This report assumes that the problem of monitoring ice volume changes and sea level changes would be the provenance of the Physical Climate and Hydrology Panel and the Oceans Panel, respectively. The solid Earth component of this problem is essential. Knowledge of the motions of the solid Earth along ocean coastlines and near the margins of ice sheets is required to determine changes in ice and water volumes. These measurements require space geodetic techniques to establish an absolute vertical reference frame for tide gauge and altimetric measurements and to monitor the deformations of the solid Earth near the margins of the oceans and ice sheets.

Satellite techniques to determine the position of surface points to sub-centimeter accuracy have important applications to the measurements of the motions of transient deformations of near-plate boundaries, near the source regions of most of Earth's largest destructive earthquakes. Earthquake-related deformations can produce uplifts of the order of several to tens of meters which can significantly alter the local and regional hydrological or coastal environment.

Space geodetic techniques have revolutionized the measurements of variations of Earth rotation (length of day and pole position). In addition to external gravitational effects, these variations reflect transfers of angular momentum between the atmosphere, the oceans, the solid Earth, and the liquid core. Increased resolution of the measurements and better global determinations of motions of the atmosphere and oceans are necessary to separate the various components controlling the variations within the spectrum of temporal variability from hours to decades. Of particular relevance to climate change is to understand better how mountain torques and surface friction couple angular momentum transfers between the oceans, atmosphere, and solid Earth. A further relevant component of Earth rotation variation to seek is that due to the transfer of mass from ice to oceans.

Contributions of EOS and Non-EOS Sensors

High Resolution Imagers

Study of components of the land surface system, including the solid Earth, requires high resolution (30 meter or better) imagers as probably the single highest priority. The requirements involve monitoring specific features of the land surface at high resolution and go beyond a need only to "calibrate" and interpret observations to be made primarily with medium resolution sensors. Besides basic functions of mapping the land surface topography, lithology, geomorphic state and age, satellite observations have the potential to monitor changes in the land surface related to the fast-acting geological processes discussed in the preceding section. This requires identification of areas where change is to be monitored, establishing baseline observations, and monitoring frequently enough with medium resolution imagers and atmospheric sensors to detect large volcanic or storm-related events. Study of the solid Earth as part of the land system also requires monitoring of components of hydrology such as river state, distributions of standing water, snow, and ice, and meteorological parameters relevant to developing regional mesoscale climatologies. The ability to see through cloud cover is essential and requires radar imaging to be continued through the EOS era.

Presently "available" high resolution data include Landsat Thematic Mapper, ERS-1 SAR, and SPOT, but these exist now either as expensive commercial products or have very limited distribution and spatial coverage. Without de-commercialization and placement in the public domain, Landsat or SPOT data can only be acquired for limited areas for limited time periods. The access to multi-temporal coverages over large regions, restricted only by the abilities of the researchers and computers to deal with the data volumes, is a capability that so far has not existed and would probably not exist with commercial satellite imagery. ERS-1 and ERS-2 SARs, JERS-1 AVNIR and SAR, and RADARSAT will provide extremely valuable pre-EOS data to help define the monitoring strategies, but these sensors will operate for limited periods only and may have only limited regional coverage.

The long-term monitoring capability and accessibility of EOS data, combined with the advanced high resolution capabilities of ASTER, the EOS SAR, and HIRIS, would revolutionize the study of the land surface system. Given the decisions (1) to place EOS SAR outside the EOS funding considerations for the October Payload Advisory Panel Meeting and (2) to place HIRIS on a later platform, solid Earth sciences and the other components of the land system have ASTER as the remaining high resolution imager for early flight. We strongly support this instrument for solid Earth studies. The combination of visible, near-infrared, and thermal infrared, the high spatial resolution, and the stereo capability make ASTER an extremely powerful tool for both volcanological and geomorphic/tectonic studies of the land surface.

The unique and potentially revolutionary spectroscopic capabilities of HIRIS to discriminate minerologies of the surface would have a broad impact on solid Earth studies of the land surface, not only with respect to geologic mapping but particularly in regard to the detection of change related to the effects of wind, water, ice, volcanoes, earthquakes, and other transient impacts on the exposed soil and rock component of the land system.

The Panel recognizes the unique multi-wavelength and polarization capabilities of the EOS SAR to penetrate clouds and to image important features of the landscape. If the EOS SAR were descoped, the multi-frequency, multi-look angle capabilities might be more important to solid Earth sensing than the multi-polarization capability. Multi-look angle capabilities are seen as the highest priority of the EOS SAR for rapid site-revisit capability.

The combination of physical properties sensed by SAR and chemical properties sensed by HIRIS has the potential to date the ages of geomorphic surfaces and thus provide a completely new and vast data set to determine rates of erosion and deposition. The potential for this type of work has been demonstrated and continues to be developed through extensive site work with sensors such as Landsat and airborne instruments such as AIRSAR, TIMS, and AVIRIS for areas mainly in the western USA.

Volcanoes pose specific requirements to detect and measure the temperatures and morphologies of lavas and plumes. Critical to the analysis of both explosive and lava-producing eruptions is the temporal perspective of the activity provided by the EOS sensors. Gas release during an eruption may vary on time scales of a few hours and can be related to the segment of the subsurface magma reservoir that is being tapped at different stages of the eruption. In the case of lava flow fields, magma production rates, the cooling history of lava flows, and the spatial distribution of activity, provide crucial information on the internal structure of the volcano (magma chamber size, location of fissures) and the rheological properties of the melt. In the case of lava flow studies, the high spatial resolution of EOS sensors is an essential attribute due to the relatively small size (a few tens to hundreds of meters) of the phenomena. In addition, the determination of pixel-integrated temperatures (e.g., lava flows that have sub-pixel-sized areas at more than one temperature) require both high spatial resolution and high spectral resolution. ASTER and HIRIS are vital for these temperature determinations. Although HIRIS is not as valuable for the volcanic studies as ASTER, due to the absence of thermal infrared measurements, HIRIS could obtain valuable temperature data on lava flows and active lava domes.

Medium Resolution Monitoring Imagers

MODIS-N is required to detect change by monitoring frequently on regional to global scales such phenomena as thermal anomalies associated with volcanic eruptions, large dust storms, or other rapidly occurring land surface processes. MODIS-N can thus be used to locate specific areas of significant change that can then be examined with high resolution instruments to determine the nature and magnitude of change. MISR's capabilities to determine the amounts of particulates in the atmosphere are required for studies of volcanic eruptions and processes of wind erosion and transport.

Topography

Topography is perhaps the single most important land surface characteristic that determines the climatic, hydrologic, and geomorphic regimes. The limited number of digital elevation models that have recently become available are already stimulating new areas of interdisciplinary study of the terrestrial land surface combining geomorphology, tectonics, and climatology. The urgent need to obtain new digital topographic data is described in several reports and will not be repeated here. The Solid Earth Panel strongly supports requests to the Department of Defense to release its enormous DTED data base of topography, and also strongly supports the NASA initiative to fly a special topographic satellite mission as an Earth Probe. Analysis of SPOT stereo and new stereo data to be derived from Japanese satellites (e.g., JERS-1 and ADEOS) will also contribute to developing a global topographic data base.

The capabilities of ASTER, EOS SAR, GLRS-A, and MISR to obtain elevation data make these instruments particularly attractive to the solid Earth community. ASTER with its high spatial resolution (15 m pixel) and fore-and-aft pointing capability is particularly attractive, while the EOS SAR used either in interferometric or stereographic modes provides data in areas of continuous cloud coverage. GLRS-A's highly accurate elevation profiles will provide unique monitoring data on a number of important features, including river and lake regimes, land slides, wind erosion, and coastal features, and will provide unique capabilities to identify and measure elevations of relict coastline and lake shore markers. Because it is a profiling instrument, GLRS-A would be of greater use to the land community if the EOS orbit were not exact-repeat, thereby enabling a larger fraction of the land surface to be studied. Particularly in the case of ice sheet volume determinations, the larger number of orbit overlaps in non-repeat orbits will enable a more accurate measure of ice topography. MISR will be able to obtain elevation data on a 240 m grid, which, although lower in resolution than ASTER or the EOS SAR, will be obtained continuously and will be useful for obtaining a uniform global data base.

Topography of volcanic landforms is a major attribute of volcanism that can be addressed by EOS. Digital elevation models (DEM's) can be derived from stereo data collected by ASTER, HIRIS, or MISR, and from interferometric measurements made by the SAR. Particularly exciting is the capability to measure topographic change using double-difference radar interferometry to measure the deflation/inflation rates of volcanic craters and rift zones, or to determine the spatial distribution of new lava flows or collapse craters created during an eruption.

The topography of evolving volcanic plumes represents a special problem and requirement. The capabilities of ASTER and MISR to provide stereo views of short-lived phenomena that change on time scales of a few hours — the transient eruption plume heights and morphologies — are essential for adequate modeling of eruption dynamics. GLRS-A will also provide valuable plume height measurements when the nadir-looking profile crosses the plume.

Remote Site Monitoring

The Wide Band Data Collection System (WBDCS) presents the opportunity to transmit data from remote sites, such as from seismograph stations, water level gauges on coastlines, lakes, or rivers, ground meteorological stations, and other types of ground sensors, to the EOS data processing system. This would be of great value in the detection and study of events such as volcanoes, earthquakes, floods, and other geomorphological events and changes. In remote areas, the early detection of seismic events related to volcanic eruptions via WBDCS will enable observations of these sites by other EOS instruments to be initiated early in the evolution of the activity. Since the WBDCS system was designed for the transmission of high sampling rates of seismic data, abundant capability is available for the substantially lower data rates generally required for hydrological and meteorological monitoring.

Satellite Geodesy

The measurements of sea level and ice volumes require accurate control of satellite orbits, geodetic level measurements of the vertical movements of the land around the oceans and ice sheets, and the establishment of a uniform global reference frame for vertical movements. These objectives are well discussed in several reports such as the Coolfont Report (NASA, 1990, and Bilham, 1991). Bilham argues that characterization of annual mean sea level with an uncertainty of a few millimeters should be possible by the end of the century with a combination of available space-and ground-based geodetic techniques, a new more uniformly dispersed network of tide gauges, and instruments of the EOS class including ALT, GGI, and GLRS-A and Earth Probes such as ARISTOTELES. The tide gauges need to be tied to a global reference frame based on measurements of absolute gravity, very long baseline interferometry (VLBI), Satellite Laser Ranging (SLR), Global Positioning System (GPS), and GLRS-R. ALT class measurements of dynamic ocean topography would be necessary to extrapolate the tide gauge data to large areas of the oceans. The related problem of determining ice sheet volume changes requires GLRS-A class measurements of ice topography with accurately modelled orbital parameters and GLRS-R class measurements of vertical deformations of the solid Earth near the ice sheets. The proposed FLINN network would be an integral part of this system of measurements.

The application of satellite geodesy to tectonic problems was pioneered by the NASA Geodynamics Program, and modern work with the Global Positioning System (GPS) is expanding to many tectonically active regions with networks of benchmarks with separations of the order of tens to hundreds of kilometers and repeat times of observations of 1-2 years. The spatial and temporal densification of such measurements in earthquake-prone regions is required to detect deformations possibly precursory to destructive earthquakes, to understand better the physical mechanisms of earthquake generation, and to determine the motions of the ground that affect coastline and hydrological environments. The GLRS-R instrument provides this densification in both time and space by the use of permanently sited passive retroreflectors on the ground and by having the active range measuring system in the satellite. This strategy is quite different from that used in GPS surveys and thus adds an important complementary capability for the measurement of Earth deformation.

Related Atmospheric and Oceanic Sensors

The injection of volcanic gases and aerosols into the upper troposphere and lower stratosphere may have a significant input on atmospheric chemistry. Several EOS instruments are valuable for the analysis of volcanic emissions. MISR and EOSP will be particularly important for the observation of aerosols. SAGE, TES, and MLS will be required to determine the concentration of SO_2 and the rate of dispersal around the globe. Modeling the dynamics of the eruption plume and the rate of release of SO_2, HCl, CO, H_2O and other gases relates to the magnitude of the eruption, the magma chemistry, and the tectonic setting of the volcano. The use of MLS and TES to monitor the abundance of gas species (particularly SO_2, HCl, CO, and H_2O) that are exsolved during an eruption enables not only the residence time of magma within the magma chamber to be assessed, but also permits the role of the tectonic setting of the volcano to be considered.

LAWS, STIKSCAT, and ALT are important to determinations of momentum transfers involved in Earth rotation variations, while LAWS, AIRS, and MIMR would be important to determinations of regional climates over land areas required by solid Earth land surface studies.

Priorities

It is important to understand that the priorities discussed in this section reflect scientific considerations convolved with the financial and instrument readiness questions that were subjects of discussion during the 1991 meetings and with the evolution of scientific priorities for EOS from the original "Earth system science" to the more recent emphasis on "global change" and "climate change."

The Solid Earth Panel proposed in Seattle that a first platform composed of ASTER, MODIS-N, MISR, and GLRS-A, flying with a 10:30 AM crossing time, could be launched as early as 1997. This would provide an early science return from a package with direct application to policy decisions and to the development and validation of process models and detection of change in the critical land surface system and ice caps. In the detection of change, ASTER would provide a major technical advance and valuable continuity in the high resolution global monitoring record that started with MSS. The high resolution sensors would also provide essential information for calibration of nearly all of the down-looking EOS sensors. Substantial reduction of the cost of the package would be obtained because ASTER is provided by an international partner, Japan. However, significant delay in scheduling of this instrument on later EOS platforms may not be possible. Our priority ordering of the four instruments for the early package would be as follows: (1) ASTER, (2) MODIS-N, (3) MISR, and (4) GLRS-A.

Additional high priorities proposed to fly as soon as possible include (1) EOS SAR, (2) HIRIS, and (3) GLRS-R, in that order of priority. These instruments are considered critical for solid Earth sciences. We strongly support efforts to obtain extra-NASA support for future development of GLRS-R.

Atmospheric instruments of great value to solid Earth sciences include for the analysis of volcanic eruption plumes (in order of priority), (1) MLS, (2) SAGE III, and (3) TES; for the determination of regional climatologies AIRS, MIMR, and LAWS; and for the study of the Earth's rotational momentum budget, LAWS, STIKSCAT, and ALT. ❐

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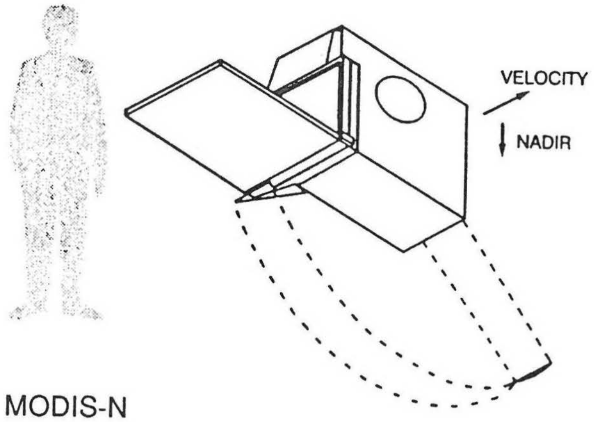
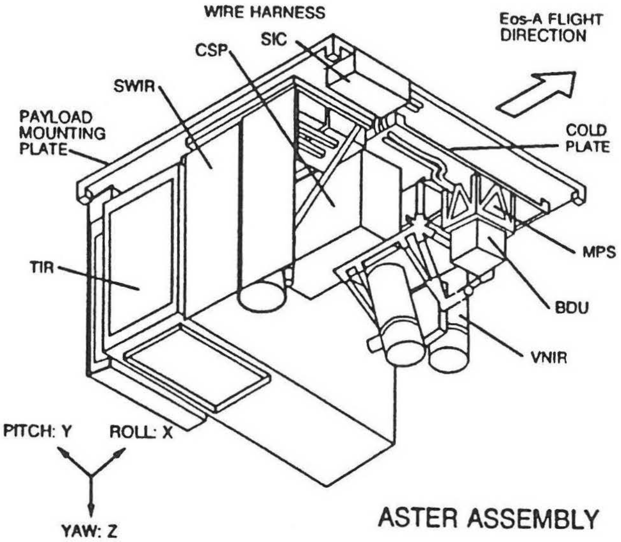


MODIS-N



ASTER ASSEMBLY

THE EARTH OBSERVER

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The Earth Observer Staff:
Executive Editor: Charlotte Griner
Technical Editor: Renny Greenstone
Managing Editor: Winnie Humberson
Distribution: Linda Carter

ASTER Science Team Meeting — An International Partnership

Dave Nichols,
Manager, JPL ASTER Science Project

The third joint Japan/United States ASTER Science Team meeting was held at the Jet Propulsion Laboratory on January 21-23, 1992. This very successful meeting demonstrated the spirit of productive cooperation between the U.S. participants and our Japanese colleagues. It was attended by 20 team members and associate team members from the U.S., a 20-person contingent, including team members, instrument engineers and data systems specialists from Japan, by 5 individuals from the EOS Project Office at the Goddard Space Flight Center, and by 2 people from the EROS Data Center.

The Japanese contractor team has completed the development of a high-fidelity instrument breadboard for all three wavelength regions—the VNIR, the SWIR, and the TIR—and is beginning development of an engineering model. As a result of this aggressive schedule, the Team focused primarily on understanding the current instrument performance characteristics, providing input to the instrument developers on science utilization concerns, and understanding spacecraft accommodation issues now that ASTER will fly on a smaller, more resource-constrained platform.

Joint Science Team meetings are held twice a year, once in the U.S. and once in Japan, with special working groups meeting more often, as necessary. This meeting, as others, began with a one-day plenary session to review the EOS Program status, instrument development status, and working group agendas. Individual working groups then met for the next 1-1/2 days, reporting to the full Team the last half of the third day. Science working groups representing oceanography and limnology, and ecosystem change/ land surface climatology did not meet at this time. By convention, the U.S. Working Group leaders provide summary reports at the U.S.-hosted meetings and the Japanese counterparts report at the meetings held in Japan.

Participants were welcomed to the meeting by Charles Elachi, JPL Assistant Laboratory Director for the Office of Space Science and Instruments, and Anne Kahle of JPL, U.S. ASTER Science Team Leader. Phil Ardanuy, representing the GSFC EOS Project Science Office, then provided an overview of the restructured EOS Program, reporting on the revised payload and the scientific objectives of the AM-1 and PM-1 platforms.

H. Tsu, Japan Science Team Leader from the Geological Survey of Japan, followed with a review of action items from the previous joint Team meeting. He laid out the issues that needed to be addressed in the current meeting, including ASTER performance, data acquisition scenarios, and selection of the forward or backward-looking VNIR for stereo. Tsu also suggested that an effort be made to systematically reject cloudy data in order to minimize the data communications and processing load and maximize the utility of the instrument duty cycle.

H. Koyama, of JAROS, discussed the effects of the EOS restructuring on ASTER.

He showed ASTER in the context of the EOS AM-1 payload configuration and discussed the current status of ASTER instrument development. The next step will be to develop a detailed engineering model. A subsystem Preliminary Design Review is planned for December 1992. However, Koyama recommended slipping that date by 5 months in order to better include the results of the engineering model development in the preliminary design, while maintaining the commitment to the NASA flight model delivery date. He also reported that NASA and the Japanese Ministry of Trade and Industry (MITI) had reached an agreement on ASTER's participation in the EOS Program, based on a letter exchange between Shelby Tilford of NASA HQ and A.Ymazaki of MITI in late December and early January.

Y. Shimizu, Nippon Electric Company, described the Visible and Near Infra-Red (VNIR) subsystems. Because of the revised orbit, with a morning, descending equator crossing, the forward-looking telescope of the VNIR was changed to backward-looking. Since the majority of the Earth's land mass is in the northern hemisphere, this provides a more advantageous look, due to sun angle and thus, scattering effects.

The Short Wavelength Infra-Red (SWIR) subsystem was described by H. Michioka, Mitsubishi Electric Company (MELCO). He reported significant progress in improving the SWIR signal-to-noise by increasing the aperture from 170 mm to 190 mm. Also, the SWIR is now in a horizontal configuration with a cross-track pointing mirror, saving mass and power.

The Thermal Infra-Red (TIR) subsystem was described by T. Maekawa, Fujitsu Corporation. At this time the issue of user-selectable instrument pointing arose and it was explained that the time required to point the instrument, in any of the three wavelength regions, was measured in minutes and not seconds, and was thought to be an event occurring no more than once an orbit. The U.S. Science Team members raised a concern that this restriction might hamper the ability to acquire data, especially for targets of opportunity, e.g., erupting volcanoes, and needs to be analyzed further.

Registration/Digital Elevation Model (DEM) Working Group

Working Group Leaders: Hugh Kieffer, H.Watanabe/ Dave Pieri, Y. Miyazaki

The Registration Working Group met jointly with the DEM Working Group. Dr. Watanabe, from the JAPEX Geoscience Institute, presented the results of simulations of the effect of pointing and positional accuracy on the accuracy of the resulting DEM. He found that 6.5 to 8.3 meters of vertical error results from every arc second of pointing error (pitch). As of now, it appears as if the ASTER requirement for platform stability exceeds the estimated spacecraft performance. The Team will do further analysis and will continue to watch the DEM accuracy issue closely. Hugh Kieffer will be preparing a comprehensive geometric error budget.

The working group recommended that, given the pointing constraints, two cross-track pointing rates be made available — one with a normal slew rate, and another faster slew rate that would be used only to acquire high value targets of opportunity when spacecraft disturbances could be justified.

Sue Jenson, from the U.S.G.S. EROS Data Center (EDC) reported that EDC is compiling information on global DEMs and is working with the Defense Mapping Agency to acquire some previously classified DEM data. The Japanese Working Group offered to produce a DEM for eastern Asia (Indonesia to Kamchatka) using 4000 ASTER scenes over a 5-year period.

Calibration/Validation

Working Group Leaders: Philip Slater/Y.Yamaguchi

Phil Slater commended all of the Japanese vendors on progress made in developing calibration plans and analysis procedures. He expressed concerns about the VNIR instrument aperture sampling, and about the lack of redundancy of in-flight calibration sources in the SWIR design. NEC and MELCO will be evaluating some suggested changes. Stuart Biggar, University of Arizona, reported on portable radiometers that could be used for cross-calibration. A number of action items were generated in preparation for the EOS Project calibration review to be held in December 1992.

Atmospheric Correction

Working Group Leaders: Frank Palluconi, T. Takashima

The Atmospheric Correction Working Group is developing revised plans for acquiring moisture, ozone, and temperature profiles, now that they are no longer available from AIRS. Plans are being investigated that may use NOAA weather satellite data, and moisture and temperature profiles from standard atmospheric models in the correction of the TIR data. The working group also plans to investigate the use of total-column and profile retrievals from MODIS-N.

Temperature-Emissivity

Working Group Leaders: Alan Gillespie, S. Rokugawa

The objective of the Temperature-Emissivity Working Group is to select a set of standard algorithms for the creation of ASTER TIR image products. Alan Gillespie discussed the impact of the loss of AIRS from the platform. Plans were developed for testing algorithms with airborne-simulator data sets for field sites that have been well characterized by standard remote sensing field methods. Gillespie reiterated the need for a spectral library that includes TIR data as well as VNIR and SWIR data for the development of these algorithms and is putting together a small test scene created from laboratory emissivity data.

Data Receiving, Processing and Archiving/ Operations and Mission Planning

Working Group Leaders: Graham Bothwell, I .Sato/ Graham Bothwell, H. Tsu

In the Mission Operations Working Group meeting, Dr. Watanabe presented an analysis of the probability of acquiring a cloud-free scene of an arbitrary location at some time within the 5-year mission. His analysis showed that without careful planning, the chances of acquiring cloud-free scenes of most of the Earth's land surfaces were very low.

The flow of data between the U.S. and Japan was discussed with several different options for data transport and locations of data processing being considered. One interesting idea put forth was to have two different transport modes, one for high priority data and another for normal priority data. The issue was raised as to the existence of Japanese or U.S. requirements for direct data downlink. No clear requirements were identified at this time, but that could change if current assumptions change regarding TDRSS availability, and EOS Data Operations and Communications System (EDOCS) services.

Geology

Working Group Leaders: Lawrence Rowan, Y.Yamaguchi

The Geology Working Group recommended strongly that whatever steps possible be taken to increase the SNR of the SWIR; increasing the aperture to 200 mm if possible, and utilizing a high gain setting for channel four. The Japanese indicated that there were already plans to use the 190 mm aperture and that the present design includes a selectable gain (up to 3x) for the SWIR. The Group also recommended that the instrument be capable of supporting four acquisition modes: 1) day mode with the VNIR, SWIR and TIR operating; 2) night mode with only the TIR operating; 3) night volcano mode with the TIR and SWIR operating; and 4) day emergency mode with the VNIR operating, potentially at a large off-nadir angle.

Airborne Sensors

Working Group Leaders: Simon Hook, S. Rokugawa

The Airborne Sensors Working Group reviewed updates on the airborne MODIS-N simulator, TIMS, and the Airborne ASTER Simulator (AAS), which is being developed by the Geophysical Environmental Research Corporation for the Japanese. Early problems with the AAS include data dropouts and limited data recording capacity. Simon Hook urged U.S. Team Members to submit requests to him immediately for 1993 (and later) AAS data from Japan.

The Next Meeting

The next Joint Science Team meeting will be held the week of June 22 in Japan following the 11th ASTER Platform Accommodations Meeting. ❐

LAWS Science Team Meeting

Wayman E. Baker
LAWS Science Team Leader
NOAA/NMC

The LAWS Science Team met on January 28-30, 1992 in Huntsville, Alabama. The meeting was attended by 10 science team members, one associate team member, and 64 other people from NASA Headquarters the NASA/Marshall LAWS Project Office, the NASA GSFC EOS Project Office, the Department of Energy, the U.S. Army, France and private industry.

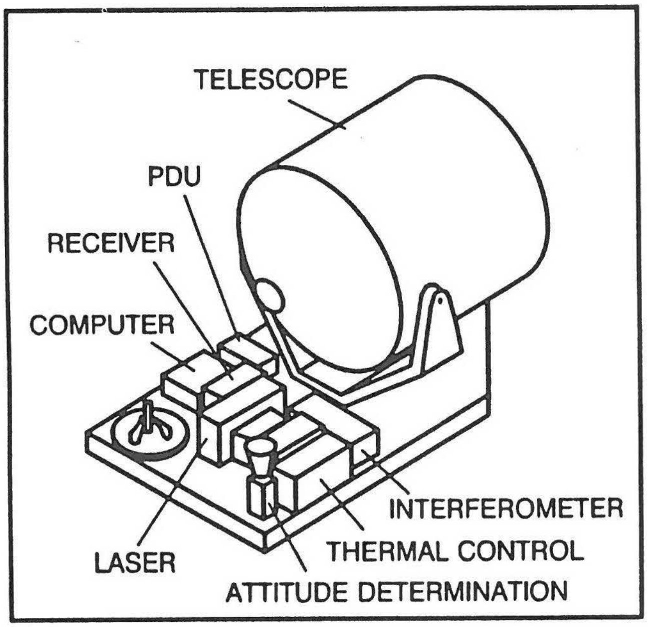
Highlights of the meeting included presentations by Lockheed and GE personnel on the LAWS system and breadboard design update and performance. The contractors initial 21-month Phase B instrument design studies are now nearing completion.

A major focus of discussion was the science implications of a possible descoped instrument (e.g., a 4 J laser instead of the 15-20 J baseline system and a 0.75 m telescope rather than one with a diameter of 1.5 m). At the request of NASA Headquarters, the impact of a descoped LAWS on the primary mission objective of providing global tropospheric winds for assimilation into atmospheric general circulation models is being assessed through observing system simulation experiments (OSSE's). Preliminary OSSE results obtained at NASA/GSFC by Robert Atlas utilizing simulated LAWS winds prepared by Dave Emmitt (Simpson Weather Associates) indicate a substantial science impact would still be present with a descoped LAWS, again confirming the importance of wind measurements for data assimilation. Further work is underway to improve the realism of the LAWS OSSE's, which will be conducted at both NASA/GSFC and Florida State University.

The results of an ESA-funded study on Doppler lidar winds was presented by Andrew Lorenc (United Kingdom Meteorological Office) which indicated the advantage for the objective analysis of LAWS winds measured with a conically scanning telescope design as opposed to the fixed telescope approach.

A special executive session was held the afternoon of January 28 with Department of Energy personnel to explore potential NASA/DOE collaborations on LAWS. Further discussions are planned.

The next LAWS Science Team Meeting is scheduled for July 1992 in the Cape Cod area. ❐



LAWS

UARS Data Illustrates Link Between Chlorine and Ozone Depletion

Jessie Katz

Early results from the Goddard-managed Upper Atmosphere Research Satellite (UARS) have confirmed the link between the presence of chlorine monoxide and the depletion of ozone in Earth's upper atmosphere.

Data from the satellite have provided the first global-scale picture of the distribution of chlorine monoxide in the lower stratosphere.

The UARS, launched by Space Shuttle Discovery on September 12, 1991, is studying the upper atmosphere to better understand the processes at work in this vital region of the Earth's environment. According to Carl A. "Skip" Reber, UARS Project Scientist, these early results indicate "UARS is a powerful new tool for detecting and tracking ozone depletion and the factors that cause it."

UARS has helped show that the more chlorine monoxide present, the less ozone will be observed. Chlorine monoxide, in the upper atmosphere, results from the breakdown of man-made chlorofluorocarbons by the sun's ultraviolet radiation. UARS has observed high chlorine monoxide over Antarctica, while simultaneously measuring the ozone depletion that accompanies it. These first results from the UARS were obtained with the Microwave Limb Sounder (MLS), one of the 10 scientific instruments aboard the satellite. MLS detects microwave radiation emitted from chlorine monoxide, ozone, sulfur dioxide and water vapor in the atmosphere. That radiation is then analyzed to produce chemical concentration and temperature data at altitudes throughout the upper atmosphere.

The MLS also is seeing the effects of the large eruption of Mount Pinatubo in the Philippines on June 15, 1991. The volcano injected huge amounts of sulfur dioxide into the stratosphere, the remnants of which appear to the MLS as a band of high sulfur dioxide concentrations over the tropics. ❐

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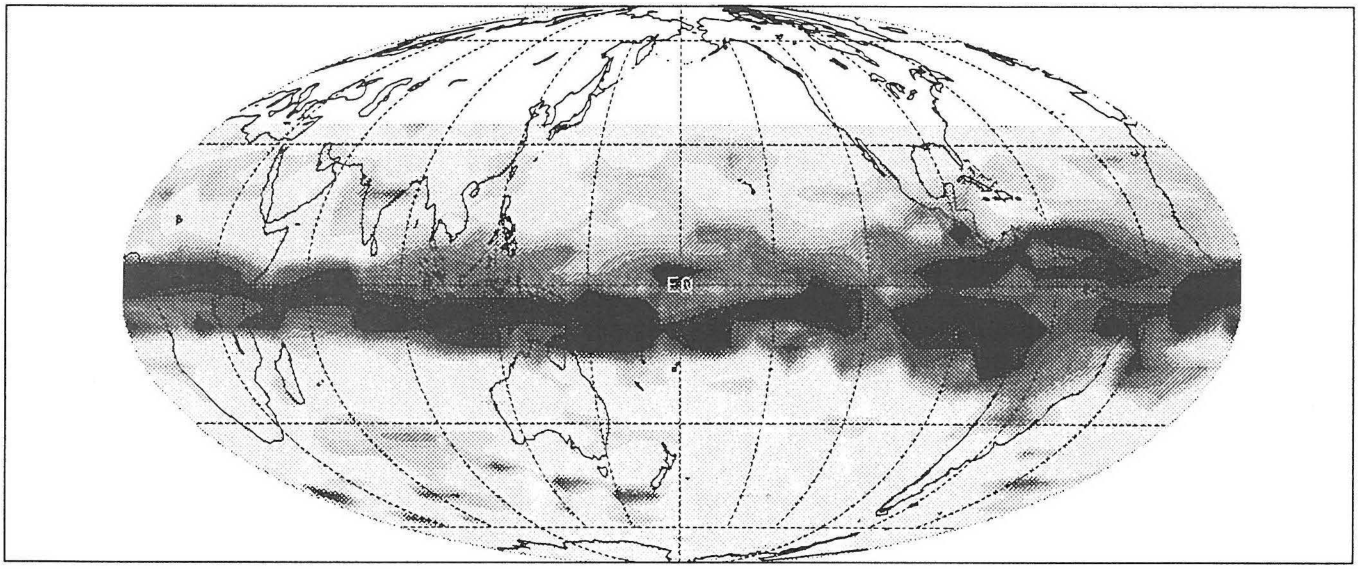


Sulfur dioxide near 25 kilometers (15 miles) altitude from the eruption of Mt. Pinatubo as observed by the Goddard managed Upper Atmosphere Research Satellite (UARS) on September 21, 1991. The volcanic plume appears as a belt of high concentration (dark areas) in the tropics.

Greenhouse Effect Detection Experiment (GEDEX)

Robert A. Schiffer,
Earth Science and Applications Division
Office of Space Science and Applications
NASA Headquarters

In May 1989, the Enhanced Greenhouse Effect Detection Project was proposed as a NASA-sponsored initiative in support of the Space Agency Forum on the International Space Year (SAFISY: 1992). Project objectives included the determination of specific signatures of an enhanced greenhouse effect; the verification of the signatures in historical data sets of conventional climate data and space-based measurements; the development and improvement of processing methods and algorithms for detecting the greenhouse effect from space observations; and the development of proposals for an international enhanced Greenhouse Effect Detection Experiment (GEDEX). In accord with the informally structured, cooperative format adopted by SAFISY, several activities and projects have been initiated since May 1989 that contribute to the broad objectives of GEDEX.

The "greenhouse effect" is accepted as an undisputed fact from both theoretical and observational considerations. Solar radiation reaches the top of the atmosphere in the form of shortwave electromagnetic radiation; the solar energy flux is about 1368 W/m^2. Because of its spherical shape, at any instant the Earth receives, on average, half the incident solar flux (i.e., 684 W/m^2). Because of the Earth's rotation, the average radiative flux received over a day-night cycle is half of this value, i.e., about 342 W/m^2. Approximately a third is reflected by the atmosphere and the Earth; the rest is absorbed. The energy absorbed by the Earth must be balanced by outgoing radiation from the Earth (terrestrial radiation) in the form of longwave invisible infrared energy.

Computations indicate that the Earth's average surface temperature (~15° C) would be -18° C were it not for greenhouse gases (GHGs) such as water vapor (H_2O, ~1% of the atmosphere) and carbon dioxide (CO_2, ~0.04%). The validity of these calculations is further verified by the observed surface temperatures of Venus (477° C) and Mars (-47° C), whose atmospheres contain large concentrations of greenhouse gases (>90% CO_2 for Venus and >80% for Mars), without which their surface temperatures would be -47° C and -57° C, respectively. These numbers translate into a greenhouse heating effect of approximately 33° C for Earth, 524° C for Venus, and 10° C for Mars. There are, of course, notable differences among the three planets. For example, on Earth, water can exist in three forms—vapor, liquid, and ice. This introduces more complex thermodynamic mechanisms for the distribution of heat than if there were no phase changes possible.

In the Earth's atmosphere, the dominant greenhouse gas is water vapor. The atmospheric water vapor content is in equilibrium between evaporation (and evapotranspiration) and precipitation. For any given surface temperature, the latter is determined by kinematic, thermodynamic, and convective (clouds/precipitation) processes. Clouds are simultaneously strong infrared warming and shortwave cooling agents.

Both water vapor and clouds are variables that respond to changes in surface temperature that are "forced" by other means, such as the increasing concentrations of anthropogenically injected greenhouse gases: CO_2 (from fossil fuel burning), CH_4 (from agriculture and livestock), CFCs (from industry), etc. These considerations have resulted in the notion of an "enhanced" greenhouse effect, over and above that due to such naturally occurring greenhouse gases as water vapor.

The specific concern today is that the exponentially increasing concentrations of anthropogenically introduced greenhouse gases will, sooner or later, irreversibly alter the climate of the Earth, and thereby disrupt global weather distribution, agricultural production, water supplies, and other economic and social activities. Over the last five years, substantial worldwide efforts have been directed toward (a) determining whether the climate has changed from preindustrial times, when anthropogenic greenhouse gas concentrations were only about half of the present concentrations; (b) searching for the enhanced greenhouse effect; and (c) developing sophisticated mathematical models to predict future global climate changes in order to guide national and international policy decisions.

Detecting climate change has been complicated by uncertainties in historical observational measurements, even though all independent analyses conclude that the global average near-surface temperature has increased by about 0.5° C over the past 100 years. Identifying the cause of this change has been one of the primary objectives of recent research. The current hypothesis is that the observed climate—in particular, the change in global average temperature—is due to an enhanced greenhouse effect. This contention is supported by state-of-the-art climate models run on the most powerful supercomputers available. That is, the change simulated by the models with enhanced greenhouse gas forcing is consistent with observations. This hypothesis forms the basis for accepting the possibility of future climate states predicted by climate system models for which a doubling of equivalent CO_2 yields an increase in global average temperature of 1.5° C to 4.5° C at equilibrium.

However, there are uncertainties arising from the various approximations and assumptions made in mathematically depicting the physical world in the current generation of climate models. At issue is the manner by which other competing (with or against GHG) forcing or feedback processes are quantified, parameterized, and incorporated in the models. In particular, there are serious questions about water vapor feedback, cloud feedback, aerosol effects, and the interactions among the atmosphere and the ocean, land surface and vegetation, and the cryosphere. At present, much of the global warming (about 70-80%) simulated and predicted by climate models is due to a positive feedback from an increase in water vapor and to a decrease in total global average cloud amount as a result of initial warming from the "direct" enhanced greenhouse effect. These effects depend on how the modeled atmosphere handles these feedback processes, and not all models agree on their magnitude—or, sometimes, even on their sign. Furthermore, the observed global warming signal is still within the range of observed (from paleoclimatic evidence) and modeled natural variability of climate.

Thus, the primary question for the GEDEX project is: How can climate change and enhanced greenhouse effects be unambiguously detected and quantified? To help answer these questions, the GEDEX project was conceived to promote observational experiments, data analysis, and modeling research to reduce uncertainties in existing assessments of climate change and enhanced greenhouse effects.

The purposes of the GEDEX Atmospheric Temperature Workshop, held in Columbia, Maryland, July 9-11, 1991, were to obtain a measure of progress in and to recommend actions required for the following:

- consolidation and documentation of existing data sets and analysis of global climate change (emphasis on temperature);
- assessment of ambiguities and uncertainties;
- review of the linkages between temperature change and plausible cause-and-effect factors (e.g., greenhouse gas forcing, other climate forcing, feedback processes);
- discussion of further research, analysis, and monitoring required; and
- initial steps toward the development of a "fingerprint" approach to the detection of climate change and enhanced greenhouse gas (GHG) effects, based on available evidence from climate models and paleoclimate reconstructions.

Temperature was selected as the focus for this first GEDEX Workshop, both because it is the most widely used measure of climate change and GHG effects, and because of its ostensibly direct relationship to changes in the atmospheric and surface radiation budget.

The Workshop addressed the primary issues involved in the detection of climate change and enhanced greenhouse effects, with the global atmospheric temperature record as a unifying theme. The workshop participants concluded that there were compelling needs to (a) better assess uncertainties in the observational record of climate change; (b) quantify climate sensitivity to GHG and other forcings; (c) improve observation and detection capabilities, using space-based and surface-based techniques, to monitor climate forcing and feedback processes; and (d) improve parameterization of forcing and feedback processes in climate models.

It was noted that several international programs address various areas of the scientific objectives of GEDEX , e.g., the World

Climate Research Programme (WCRP) and the International Geosphere-Biosphere Programme (IGBP). In particular, there are projects designed to scrutinize climate system processes, such as TOGA-COARE (atmosphere-ocean interaction), WOCE (world ocean circulation), ISCCP (cloud climatology), ISLSCP (atmosphere-land surface interactions), GEWEX (global energy and water cycles), and TRMM (tropical precipitation). Workshop participants, therefore, felt that GEDEX should provide a focus to channel resources and direct research on topics relevant to the objectives of GEDEX, but should avoid duplicating existing national and international institutional structures. Examples of appropriate subject areas are climate sensitivity; climate processes, such as water vapor feedback, cloud feedback, and aerosol-radiation feedback (e.g., using Pinatubo as a case study); atmosphere-ocean coupling on long-time scales; biogeochemical cycles affecting atmospheric concentrations of greenhouse gases; observational and analysis projects for the detection of climate change and enhanced greenhouse effects, including second and higher order variables; and natural climate variability.

As a first initiative, a comprehensive GEDEX data set containing a wide spectrum of climatic variables will be prepared and distributed on CD-ROM by NASA to the climate research community in early 1992. ❐

The Role of the Land Processes DAAC in EOSDIS

R. J. Thompson
EROS Data Center

The EOS Data and Information System (EOSDIS) is NASA's new information system for Earth science data. The goal of the EOSDIS is to provide easy, reliable access to EOS data by the Earth science community. To support the various scientific disciplines, the EOSDIS will channel each type of EOS instrument data to a facility that already has an Earth science research and data management responsibility. The EOSDIS will be a system of data archiving, product generation, and information management services distributed across a network of eight Distributed Active Archive Centers (DAAC).

Each DAAC was selected to take advantage of resident discipline-specific expertise (for example, atmospheric science, ocean processes, global hydrology, or land processes), an existing data management infrastructure, and an institutional commitment to data management for the global Earth science community. Key elements of each DAAC will be determined as the program evolves toward a prototype of the EOSDIS. Each DAAC will be organized around three interrelated functional responsibilities: data storage and dissemination, product generation, and information management. The Data Archive and Distribution System will ingest and validate sensor data, archive the data on state-of-the-art mass storage media, and store the archived data set for generation of requested products. The Product Generation System will apply preprocessing, registration, and product generation algorithms (developed by the scientist or sensor instrument specialist) to the archival data set to generate products. The Information Management System (IMS), the most visible element of EOSDIS, will provide consistent, standardized access to the archives of both pre-EOS and EOS data, regardless of how these data are distributed among the DAAC's.

The Land Processes DAAC is located at the U.S. Geological Survey's (USGS) EROS Data Center (EDC), in Sioux Falls, South Dakota, based upon compatibility of DAAC responsibilities with the Center's history of managing satellite remote sensing data, other Earth science data, and related derivative products.

EDC's responsibilities in support of EOSDIS include production of land-related products derived from partially processed Moderate Resolution Imaging Spectrometer (MODIS) data, as well as from unprocessed data acquired by the Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER), the High Resolution Imaging Spectrometer (HIRIS), and the Synthetic Aperture Radar (SAR). Although the DAAC's primarily are responsible for EOS data and derivative products, they also must provide access to existing data necessary for pre-EOS scientific investigations and algorithm development. Systems to process each of the EOS data types will be prototyped, where possible, by using existing pre-EOS data sets to develop experimental products that model anticipated EOS product specifications.

The primary objectives of prototyping, in addition to evaluating systems for archiving and product generation, are to improve access to existing data and to develop a DAAC infrastructure to assist the scientific community in obtaining pre-EOS and EOS data products. To meet these objectives, current DAAC development tasks are amalgamated into a project to produce a prototype "Version 0" of EOSDIS by 1994, then to phase Version 0 results into Version 1 of the EOSDIS Core System (ECS) as developed and implemented by the ECS contractor. Pre-EOS data to be archived and processed at the Land Processes DAAC include Landsat, Advanced Very High Resolution Radiometer (AVHRR), topographic, Airborne Visible and InfraRed Imaging Spectrometer (AVIRIS), and Thermal Infrared Multispectral Scanner (TIMS) data.

Management of the Landsat archive of approximately 3,000,000 items located worldwide has provided the EDC with invaluable experience in cataloging, retrieving, and browsing large volumes of image data. The Landsat archive also is a rich source of precursor data for pre-EOS science, and Landsat products illustrate potential applications of future EOS products. To exploit that potential, the Land Processes DAAC is participating in a Landsat Pathfinder Project to process selected Landsat data for specific pre-EOS scientific objectives and to provide data sets for validating prototype algorithms and products.

An 18-month program will begin in April 1992 to compile daily AVHRR coverage, at 1-km resolution, of all land masses of the world. Compilation of this data set, originally requested by the Land Group of the MODIS Science Team, has been endorsed by other scientific coordination groups such as the International Geosphere/Biosphere Programme and the Committee on Earth Observing Satellites. Because of the magnitude of this data collection task, NASA, NOAA, and the USGS are cooperating with the European Space Agency, the Australian Commonwealth Scientific and Industrial Research Organization, and approximately 30 worldwide AVHRR receiving stations to collect daily coverage and periodically transfer it to the Land Processes DAAC for processing.

Figure 1 illustrates footprints for the receiving stations selected for maximum efficiency of data acquisition.

The Land Processes DAAC also is collecting and documenting information about sources of digital topographic data that may be available for global change research. For the North American Continent alone, compilation of complete topographic coverage requires coordination with several national and international agencies, with each agency supplying data that differ in source, composition, format, and accuracy. The many global sources of digital topographic data will be contacted to acquire information about data prices, data formats, collection procedures, and contact points. The results of these investigations will be incorporated into the Version 0 IMS directory and data guide to improve science user knowledge of, and access to, global topographic data archives.

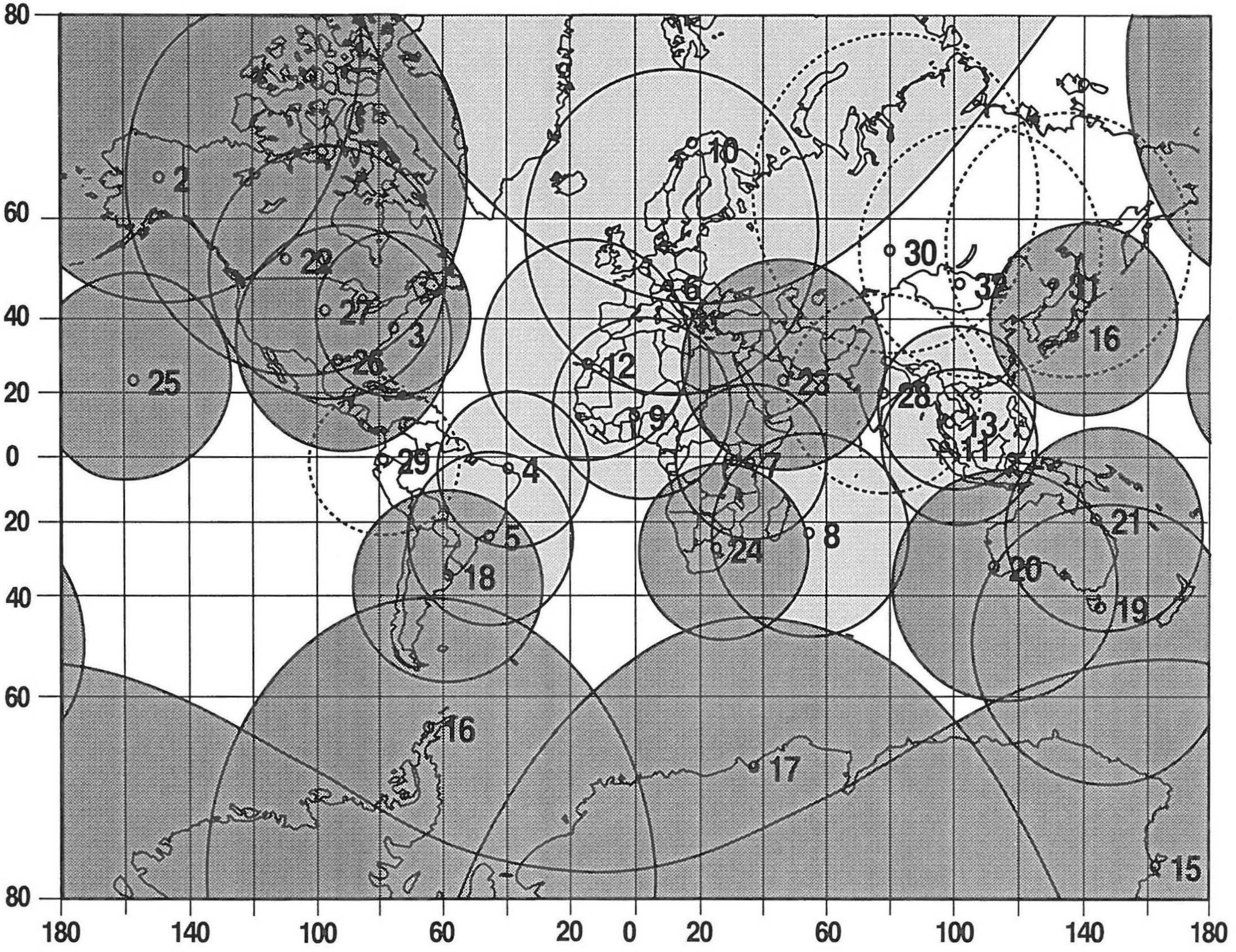
The AVIRIS and TIMS airborne sensing systems provide pre-EOS data sets as potential precursors to ASTER and HIRIS data. These instruments are deployed, in part, to acquire representative multispectral data over EOS test sites, with the data archived and processed at the Jet Propulsion Laboratory and the Ames Research Center. A Version 0 task is underway to transcribe these data archives to new media, then transfer them to the Land Processes DAAC for generation of pre-EOS products. Transcription of TIMS data will be completed in 1992 and AVIRIS data in 1993. The Land Processes DAAC will assume responsibility for TIMS and AVIRIS products in 1994-95.

As plans evolve for development of the EOS SAR, investigation of airborne SAR, European Radar Satellite, and other data sources will become more important.

These data will ultimately be processed and archived at the Land Processes DAAC, pending constraints applied by the overall EOS budget and schedule. A limited algorithm development activity for applying terrain correction procedures to radar data has been started, in cooperation with the staff at the Jet Propulsion Laboratory, the University of Alaska at Fairbanks, and other organizations, in an effort to accelerate the development of SAR processing expertise at the Land Processes DAAC.

Although the data sets described above are vitally important to pre-EOS use, perhaps the most important near-term task is the devel-

Global Land 1km AVHRR Data Set
Proposed HRPT Ground Station Network



▨ U.S. Geological Survey (USGS)   ▨ European Space Agency (ESA)   ------ Ground Station Under Consideration opment of an interoperable Version 0 IMS for the DAAC network. Linking disparate systems, which manage the data sets described above, to the DAAC network is a difficult activity. For example, to access multiple types of data, interdisciplinary EOS researchers must be able to search across multiple inventories, distributed among heterogeneous systems at different DAAC's. To support this requirement, each of the DAAC's now is prototyping cross-DAAC inventory search capabilities through a common user interface. In a related activity, the Land Processes DAAC is prototyping approaches to image data browse services, also in an interoperable environment. Experiments are being conducted with AVHRR and Landsat images to determine the most effective resolution for browse images and to illustrate the impact of data browsing on the user interface.

Finally, each DAAC must develop ways of coordinating its activities with the EOS user community. Accordingly, each DAAC has a project scientist to ensure that DAAC activities are consistent with science user requirements. The DAAC project scientist is responsible for defining a DAAC science support policy, assisting in the definition of product lines, consolidating user requirements, and communicating with the EOSDIS Science Advisory Panel, NASA program and project scientists, and instrument science teams. The Land Processes DAAC has established a Science Advisory Panel of EOS and non-EOS experts to advise DAAC management regarding activities, products, plans, and priorities. Science coordination meetings provide opportunities for the DAAC project scientists to ensure that the policies and activities of each DAAC are consistent with the overall goals of EOS and EOSDIS. ❐

Atmospheric Radiation Measurement (ARM) Program

At the invitation of the editors of The Earth Observer, Lee Somerstein, public information officer for ARM, has submitted the following article describing the DoE's contribution to the study of global change. To be added to the distribution list for ARM's monthly bulletin, contact Susan Cammann, Battelle, Pacific Northwest Laboratories, Battelle Boulevard, P.O. Box 999, MS K1-74, Richland, WA 99352, telephone 509 375 2745.

The Atmospheric Radiation Measurement (ARM) Program is part of the effort by the U.S. Department of Energy (DOE) to resolve scientific uncertainties about global climate change. Human activities and new technologies are adding carbon dioxide and other so-called greenhouse gases to the atmosphere in quantities that may be altering our climate on a global scale. The term "radiation" in the program's name refers only to *solar* radiation.

The ARM Program will ultimately select five sites. Each site will be used to establish an array of measuring instruments over an area approximately 25,000 square miles. There will be one primary measuring station of approximately 160 acres at each site, with smaller stations spread over the rest of the area.

These instruments will collect and analyze data that will help determine the effects and interactions primarily of sunlight and clouds on temperatures, weather, and climate. Knowledge gained from these measurements will contribute to a better understanding of potential climate changes by improving the computer models that scientists use to predict these changes.

The measuring instruments will be in operation for up to ten years. This is unprecedented; these types of measurements have never been taken over such a long period of time.

The ARM Program will improve our ability to predict how much our climate might change, how fast that change could occur and what the local effects of that change might be.

We have identified five general locales for sites. They are:

- southern U.S. Great Plains/ N. Central Oklahoma and S. Central Kansas,
- Tropical Western Pacific Ocean,
- North Slope of Alaska,
- Eastern North Pacific or Atlantic Ocean, and
- Gulf Stream off the coast of Eastern North America.

The environmental assessment for Site #1 is currently circulating internally for review. The operational target for Site #1 is Spring, 1992, with one new site coming on line in each of the next four years.

In a very real sense, this program will help leaders around the world make important decisions in the future about the effects of global climate change on our social, economic, and political systems. ❐

EOS Tropospheric Anthropogenic Aerosol Workshop

The following is a condensation of the EOS Tropospheric Anthropogenic Aerosol Workshop Report. Interested readers may obtain a copy of the full report by writing to ***The Earth Observer.***

The Workshop attendees were: Robert Dickinson, *chair*, U of Ariz; Thomas Ackerman, Penn State U; Ghassem Asrar, NASA HQ; William Bandeen, EOS Project Science Office, NASA/GSFC; Robert Charlson, U of Washington; James Coakley, Oregon State U; David Diner, NASA/JPL; Benjamin Herman, U of Ariz; Yoram Kaufman, GSFC; Jeffrey Kiehl, NCAR; John Martonchik, JPL; M. Patrick McCormick, NASA/LaRC; Joyce Penner, Lawrence Livermore Lab; Philip Slater, U of Ariz; Tim Suttles, NASA HQ; Larry Travis, NASA/GISS; Ming-Ying Wei, NASA HQ; and Robert West, JPL.

1. Reason for the Workshop

At the EOS Payload Advisory Panel meeting on October 24, 1991 Robert Watson of NASA Headquarters pointed out that the effects of increasing tropospheric aerosols on global climate were receiving very serious attention in the new Intergovernmental Panel on Climate Change (IPCC) update study and could have major policy implications. As a result, an EOS Tropospheric Anthropogenic Aerosol Workshop was held at the University of Arizona on December 16-17, 1991. The purpose of the workshop was to write a report advising on EOS capabilities to monitor the presence and trends of tropospheric aerosols with presently recommended EOS instruments and with the addition of the Earth Observing Scanning Polarimeter (EOSP).

2. Background on Scientific and Policy Issues Involved

The world's attention is currently riveted on the question of present and future global warming and other accompanying climate changes that are expected to result from increasing concentrations of greenhouse gases. Together, the increases experienced over the last century are equivalent to adding about 2.4 W/m^2 of energy to the climate system, with the steady state global average surface temperature response expected from this forcing in the range of 0.8 to 2 degrees. The observed temperature increase to present has been at most about 0.5 degrees (IPCC, 1990), and the time history has peculiar features such as temperatures in the Northern Hemisphere that were almost as warm in 1940 as they are now, with a remarkable cooling from the 1950's into the 1960's.

Besides carbon, another major ingredient of fossil fuel is sulfur, typically 1%-3% by weight. This ingredient oxidizes to SO_2 in combustion, and the latter is further oxidized to sulfuric acid in the atmosphere. About half the sulfur combusted in fossil fuels becomes sulfate aerosol in the atmosphere. This sulfate is removed primarily by precipitation processes. The sizes of the sulfate aerosol particles are optimum for scattering solar radiation but relatively ineffective in absorbing or emitting thermal infrared radiation; the fraction that is upscattered represents an energy loss, estimated to be as large in the global average as $1W/m^2$, but concentrated within the Northern Hemisphere (Charlson et al., 1992).

The sulfate aerosol particles also increase the numbers of droplets in clouds through their action as cloud condensation nuclei (CCN). The radiative effect of this process is difficult to quantify, but it is also estimated to reflect globally an additional 1 W/m^2 (Charlson et al., 1992).

An analysis of the effect of smoke has greater uncertainty, but reasonable estimates of the terms involved suggest that the smoke from burning of biomass and fuel wood may have radiative impacts comparable to that of sulfate aerosol. Some burning has always been present but the amounts of smoke generated have probably at least doubled over the last century.

In sum, plausible arguments can be made to indicate that current anthropogenic greenhouse warming is largely or entirely cancelled by growth of anthropogenic aerosols over the last century. However, it is not possible to establish these arguments with adequate quantification without a much more substantial and focused research program than is now happening.

Confirmation of the hypothesis that present anthropogenic greenhouse warming is largely cancelled by anthropogenic aerosols would have major policy implications: a) because carbon dioxide has a very long lifetime in the atmosphere, while the aerosols have very short time scales, continuation of fossil fuel burning should eventually lead to a predominance of greenhouse warming; b) on the other hand, with the disparate residence times of CO_2 and sulfate aerosols in the atmosphere, rapid scalebacks in fossil fuel burning could act, for up to a few decades, to accelerate greenhouse warming; c) furthermore, national efforts to reduce the sulfur emission from burning fossil fuel to combat acid deposition would have to be regarded as contributing to increasing greenhouse warming and interpretation of the present observational record in terms of a low sensitivity to climate forcing would have to be re-evaluated; that is, present observations could no longer be used to exclude the possibility of a very large future greenhouse warming.

3. EOS Aerosol Capabilities

The EOS instruments potentially contributing most to an overall aerosol program are: MODIS, MISR, SAGE-III, and EOSP. EOS needs to insure both a strong component of global monitoring of aerosol distribution over at least the 15-year lifetime of the mission, and process research adequate to characterize the physical, chemical, and radiative properties of the anthropogenic aerosols.

The workshop discussion indicated that clouds, surface reflectance, and the large variability of stratospheric aerosols were serious obstacles to remote sensing of tropospheric aerosols. MODIS with its associated cloud characterization program and assumptions regarding aerosol type can readily provide global distributions of total column aerosol opacity over the oceans where the underlying surface is near constant and near black. Scattering phase function measurements obtained by MISR will improve the quality of marine aerosol retrievals by providing independent constraints on aerosol type.

Inversion by MODIS for aerosols over land is more problematical and requires either adequately dark underlying surfaces or finding situations where aerosols are absent or negligible at times. The bidirectional measurements of MISR add strong additional information that allow surface and aerosol reflectances over land to be inverted jointly, thereby providing instantaneous characterizations of aerosols whenever cloud-free conditions are found.

Removal of the variable stratospheric background is required in order to characterize the tropospheric aerosol. The Payload Panel recommended provision of this capability through flight of two copies of the SAGE-III instrument, one on an inclined and one a on polar orbiting platform. The present workshop concurred with that recommendation.

The workshop noted that a minimal observational program for tropospheric aerosol requires that MODIS, MISR, and the two copies of SAGE are flying in the same time frame. This program requires MODIS and MISR to be on the same platform, but the polar orbiting SAGE-III could be elsewhere. The Panel considered the desirability of adding EOSP to this program. The EOSP instrument plans to provide self-contained cloud removal and adequate characterization of surface polarization signals to provide by itself a global mapping capability of aerosols. Its polarization measurement has considerable accuracy and, in principle, provides unique additional information on aerosols. However, the instrument algorithms involving polarization have not been developed in detail for a realistic terrestrial environment, so it is not possible to judge their potential efficacy.

The workshop suggested that the question of measuring aerosol properties was complicated enough to merit the development of alternative approaches. It was impressed, based upon preliminary sensitivity analysis, with the potential of the EOSP polarization measurement as an alternative means to obtain optical depth, as well as additional information on size distributions and possibly index of refraction. However, the panel was concerned with the retrievability of such information from the EOSP measurements, primarily as a result of the as yet largely unknown problems of removing polarization contributions from underlying surfaces and subpixel clouds. The possibility of reorienting the EOSP instrument from a cross-track scanning mode, which provides global coverage but observation of each point at only a single scattering angle, to an along-track scanning mode in which observations over a wide range of scattering angles are obtained at the expense of global coverage, was discussed as a means of addressing these problems.

4. Recommendations

A. That the Federal Government agencies through the Committee on Earth and Environmental Sciences (CEES) develop, in the EOS time frame, a focused national program to better characterize sources, sinks, and spatial and temporal distribution of tropospheric aerosols with emphasis on direct and indirect radiative effects. This effort would depend on EOS for remote sensing, but would also require enhancement of present aerosol observational and modeling efforts of DOE, NASA, NOAA, and NSF.

B. That the aerosol measurement efforts within EOS be further developed and focused to provide global mapping of tropospheric aerosol properties with effective and validated algorithms. This requires the separate measurement of stratospheric aerosol properties in the same timeframe as the measurement of column aerosol properties.

C. That the EOSP instrument be tentatively added to the EOS flight instruments, preferentially on the same platform as MODIS and MISR. If on the same platform, consideration should be given to the possibility of employing it in a scanning along-track mode to enhance the synergism with MODIS and MISR. The along-track mode would optimize the information content of the polarimetric observations with respect to particle microphysical properties, at the expense of EOSP's global coverage. Extension to the global scale would be provided by simultaneous MODIS and MISR observations. The addition of EOSP should be contingent on the demonstration that either, (1) with MODIS and MISR, it synergistically retrieves additional aerosol information, or (2) in the stand-alone (cross-track scanning) mode, it retrieves global aerosol properties (at minimum opacity) under realistic conditions. The workshop encouraged the EOSP team to carry out such a demonstration within the coming year. It is anticipated that demonstration of the stand-alone capability will be the more difficult of the above objectives.

References

Intergovernmental Panel on Climate Change, *Climate Change, the IPCC Scientific Assessment*, Report prepared for IPCC by Working Group 1, University Press, Cambridge, **365**pp., 1990.

Charlson, R. J., S.E. Schwartz, J. M. Hales, R. D. Cess, J. A. Coakley, Jr, J. E. Hansen, and D. J. Hofmann, Climate forcing by anthropogenic aerosols, *Science*, ***255***, **423**, 1992. ❐

EOSDIS Newsletter

Rich Bredeson
Science Software Manager

The EOS Ground System and Operations Project is publishing a newsletter, the *EOSDIS Science Data Processor*, which is intended to provide a means to communicate science data processing ideas and activities to the data processing community associated with EOSDIS. While we plan to convey project thinking, events, and direction to our readership, we also hope to generate dialog within the community and motivate responses to the Project's plans.

Three issues have been published. Articles have addressed software development environments, interfacing science software to the EOSDIS, how the project is addressing the subject of software development guidelines, UNIX and its use, networking in UNIX, electronic mail, and the IEEE Symposium on Mass Storage Systems. Future issues will contain articles that address software engineering topics such as object-oriented techniques; hardware topics such as technology advances; and project events such as working group meetings, workshops, seminars, and document publications.

If you have not received a copy of *The EOSDIS Science Data Processor*, and would like to be added to the mailing list, please contact Kelly Wetzel or Sarah Wager at Westover Consultants, Inc., 6303 Ivy Lane, Greenbelt, MD 20770, telephone (301) 220-0685, or SWAGER on GSFCmail. ❐

EOS Science Meetings

April 6-9, 1992	EOS Calibration Panel Meeting, Boulder, CO. Contact Bruce Guenther, at(301) 286-5205
April 14-16, 1992	MODIS Science Team Meeting, GSFC. Contact Locke Stuart, at (301) 286-6481
April 28-May 1, 1992	AIRS Science Team Meeting, Camp Spring, MD. Contact George Aumann, at (818) 584-2934
Spring, 1992	EOS Oceans Panel Topical Science Meeting on Air/Sea Interactions. Contact Mark Abbott, at (503) 737-4045
Spring, 1992	EOS Atmospheres Topical Science Workshop. Contact Mark Schoeberl, at (301) 286-5819
June 9-10, 1992	Graduate Student Fellowships in Global Change Research Panel Meeting, Washington, D.C. Contact Ghassem Asrar, at (202) 453-8195
Week of June 22, 1992	ASTER Science Team Meeting, Japan. Contact Dave Nichols, at (818) 354-8912
June 23, 1992	Land Science Meeting. Contact Piers Sellers at (301) 286-4173 or Darrel Williams, at (301) 286-8860

Global Change Meetings

May 4-6	Second Circumpolar Symposium on Remote Sensing of Arctic Environments, Tromso, Norway. Contact The Roald Amundsen Centre for Arctic Research, University of Tromso, Breivida, N-9000 Tromso, Norway. Phone: +47 83 45 240; Telefax: +47 83 80705.
May 10-15	"Imaging '92" IS&T's 45th Annual Conference, The Meadowlands Sheraton Hotel, East Rutherford, New Jersey. Phone: (703) 642-9090; Fax (703) 642-9094.
May 11-15	American Geophysical Union's Spring Conference, Montreal. Contact Karol Snyder, American Geophysical Union, 2000 Florida Ave. N.W. Washington D.C. 20009. Phone: (202) 939-3205; Fax (202) 328-0566.
June 14-17	ECO World 92' Conference, Washington D.C. Contact: ASME 345 East 47th Street, New York, N.Y. 10017. Phone: (212) 705-7148; Fax: (212) 705-7143.
June 15-17	First Thematic Conference on Remote Sensing for Marine and Coastal Environments: *Needs and Solutions for Pollution Monitoring, Control, and Abatement*, New Orleans, Louisiana. Contact Nancy Wallman, ERIM, Box 134001, Ann Arbor, MI 48113-4001 USA, Phone (313) 994-1200, ext. 3234; Fax (313) 994-5123, Telex: 4940991 ERIMARB
July 19-Aug 8	A NATO Advanced Study Institute, *Remote Sensing and Global Climate Change*, 7th Dundee Summer School in Remote Sensing, University of Dundee, Scotland, U.K. Contact Robin Vaughan at (0382) 23181 Ext. 4557/4912; Fax (0382) 202830; Telex 9312110826 DU G.
August 2-14	XVII Congress of the International Society for Photogrammetry and Remote Sensing (ISPRS), Washington, D.C. Concurrent to the ISPRS Congress, two other meetings will be held nearby: the ASPRS and the American Congress on Surveying and Mapping (ACSM) will conduct a conference on Global Change; the International Geographical Union will convene its 27th International Geographical Congress (IGC) during the second week. For more information contact XVII ISPRS Congress Secretariat, P. O. Box 7147, Reston, Virginia 22091.
August 24-28	The 1992 STEP Symposium-COSPAR Colloquium No. 5, Johns Hopkins University. Contact Dr. Michael Teague, Phone (301) 286-4232; Fax (301) 286-9803.
Aug. 31-Sept. 3	COSPAR Symposium on Global Change and Relevant Space Observations, Washington, D.C., World Space Congress. Contact J. Fellows/OMNET; Fax 33 1 45087867; telex 214674; Phone 33 1 45087648. (Call for papers available from World Space Congress, AIAA, The Aerospace Center, 370 L'Enfant Promenade, S.W., Washington, D.C. 20024-2518; Phone (202) 646-7451; Fax (202) 646-7508.
November 2-6	Sixth Australasian Remote Sensing Conference, *Remote Sensing and Spatial Information,* Michael Fowler Centre, Wellington, New Zealand,. Contact Stella Belliss, DSIR Physical Sciences, P. O. Box 31-311, Lower Hutt, New Zealand; Phone +64-4-5666919, extension 8693; Fax +64-4-5690067.
February 8-11, 1993	Ninth Thematic Conference on Geologic Remote Sensing: *Exploration, Environment, and Engineering,* Pasadena, California. Contact Nancy Wallman, ERIM, Box 134001, Ann Arbor, MI 48113-4001 USA, Phone (313) 994-1200, ext. 3234, Fax (313) 994-5123, Telex: 4940991 ERIMARB.

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National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771