The Restructured Earth Observing System: Instrument Recommendations

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Responding to directions from the EOS Engineering Review Committee [Friedman, 1991] and Congress, the Payload Advisory Panel for NASA’s Earth Observing System (EOS) has proposed a restructured EOS to address high-priority science and environmental policy issues in Earth system science. The panel, which met at a workshop October 21-24 in Easton, Md., is comprised of the EOS interdisciplinary investigators and chaired by Berrien Moore of the University of New Hampshire. The panel’s recommendations were submitted to NASA last week.

Although the panel’s recommended EOS program remains ambitious, it is reduced from the original plan proposed last year. While EOS will retain its emphasis on collecting observations over a 15-year period, many important measurements are cancelled, deferred, or proposed for provision by international partners. 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 may be endangered.

Instruments recommended for flight in the “early” EOS period (1997-2001) and beyond are summarized in Tables 1 and 2. The strategy of the mission combines high-priority, new measurements and the 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. For implementation, the panel recommends a set of similar, moderate-sized platforms, a suite of Earth Probes and additional free flyers, and an essential dependence on international instruments and platforms for which definitive commitments should be sought.

The recommended instruments 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 recommendation are measurements of the middle- and upper-stratosphere and measurements associated with solid Earth geophysics. While this recommendation focuses on the science program associated with instruments to be launched by NASA and international partners in the period 1997-2001 and beyond, EOS will build on the progress of satellite missions that have begun and will continue in the 1990s. EOS will provide follow-on measurements for:
- Earth’s radiation budget from ERBE (Earth Radiation Budget Experiment) and Nimbus-7;
- precipitation, snow and ice cover, and atmospheric water from TRMM and SSMI, part of DMSP;
- scatterometer observations from NSCAT, to fly on the Japanese ADEOS;
- ocean color from SeaWIFS, which continues measurements begun by CZCS;
- altimetric measurements begun by TOPEX/Poseidon;
- land/surface measurements from Landsat, AVHRR, and SPOT programs;
- operational meteorological satellites;
- stratospheric chemistry and dynamics from UARS;
- ozone from TOMS and SAGE II.

In setting priorities, the panel was guided by studies conducted by the Intergovernmental Panel on Climate Change [1990], the Environmental Protection Agency [Lashof and Tirpak, 1990], and the Committee on Earth and Environmental Sciences [1991]. The recommendation now goes to the EOS program at NASA Headquarters and the EOS project at Goddard Space Flight Center for further analysis of costs and accommodations.

Change in Funding Profile

The programmatic environment for EOS has changed since instruments were selected early in 1990 for the launch of the “EOS-A” satellite in 1998. The run-out budget through fiscal year 2000 was capped by this year’s House-Senate conference report at $11 billion, down from about $17 billion. The Congress imposed a $44 million cut on the president’s budget in FY 1991 and a $65 million cut in FY 1992, leaving an allocation for FY 1992 of $271 million. The Senate also suggested that the 1993 increment will be no more than $200 million, thus constraining the availability of funds in the near term.

The reduced funding profile for 1992-1994, coupled with a $6 billion decrease in the budget for the first decade of EOS, requires that NASA pursue only the highest-priority science and policy issues. Pursuit of these issues requires the United States to fully exploit the current operational satellites, Earth Probes, and international Space missions, and to use a more phased implementation of the EOS program. This phasing is consistent with placing the EOS instrument configuration on moderate-sized platforms and associated smaller free flyers, as recommended by the EOS Engineering Review and subsequently directed by the House-Senate conference report.

The recommended reconfiguration leads to a flexible sequence of instruments and satellite payloads to measure the most important variables without delaying the launch of NASA’s first EOS satellite beyond 1998. The strategy can adapt to the reordering of scientific priorities as our knowledge of the Earth improves. The lower budget, however, dictates increased reliance on our Japanese and European partners in the international Earth Observing System, and on instruments furnished and operated by our domestic partners, NOAA, the Department of Defense, and potentially, the Department of Energy.

Table 3 summarizes the panel’s ordering of science and policy questions. Table 4 identifies the highest-priority instruments in each category.
Tables 5 and 6 summarize the panel’s recommendations for NASA-flown payloads and sensor packages that should fly on the same platform. The panel has also considered effects on the size and implementation constraints imposed by budgets and the size of launch vehicles. The panel has also considered the potential for synergetic instrument clusters that need to fly in orbit at different times to achieve the maximum benefit from the data collected.

**Implementation Strategy**

The recommended 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. Tables 5 and 6 summarize the panel’s recommendations for NASA-flown payloads and NASA-provided instruments for flights on free flyers or international satellites. Synergetic instrument clusters have been identified that attack specific scientific problems (for example, 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, the panel has assessed technical and fiscal feasibility given constraints imposed by budgets and the size of launch vehicles. The panel has also considered the potential for synergetic instrument clusters that need to fly in orbit at different times to achieve the maximum benefit from the data collected. The instruments on the recommended implementation of the EOS Atmospheres Panel are: Tropospheric Emission Spectrometer (U.S., R. Beer); Solar Stellar Irradiance Comparison Experiment (U.S., G. J. Rottman); Tropospheric Aerosol and Gas Experiment (U.S., M. P. McCormick); and Lightning Imaging Sensor on TRMM (U.S., H. J. Christian).

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ments (MISR, AIRS/AMSU-A/AMS, and MODIS-N), in concert with vector wind stress measurements from a scatterometer (recommended for inclusion in Japan's ADEOS-2), are needed for global-scale studies of air-sea fluxes of energy and moisture. MISR, 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 for assessment of the utility and accuracy of precipitation estimates based on MISR data. MODIS-N and MISR will allow for mapping of snow water equivalent and the monitoring of variability and change of the climate and hydrological systems.

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 NASA A.M. and P.M. sun-synchronous orbits as well as the inclined orbit provided by TRMM. Another cluster on the NASA A.M. platform, 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, MOPITT, SAGE III, and HIWLS provide critical data related to tropospheric and lower stratospheric chemistry and dynamics, including troposphere-stratosphere exchanges. Measurements of the external solar forcing of the Earth system will be provided by ACRIM and SOLSTICE; however, they need not fly on any specific platform or in any particular orbit, other than sun-viewing. CERES and US, in an inclined orbit, will improve the diurnal coverage and could be implemented on TRMM-2. EOSP and SAGE III, in an inclined orbit, will similarly improve coverage.

Vapor in ocean absorption of solar radiation caused by changes in bio-optical properties can be investigated using yet another set of instruments—MODIS-N and GLI, with SeaWIFS-2 providing continuity of ocean color measurements until both MODIS-N instruments are flying. Along with vector winds from a scatterometer, this cluster will allow for more accurate estimates of ocean-atmosphere exchanges of carbon.

The recommended NASA-supported conferences were initiated with the early suite of platforms in 1997–2001. Inclusion of IMCEns was possible through development of BIO-MODIS and MODIS-T. Polar Flight of Opportunity EOSM, HIWLS, MOPTT, NSCAT-2, and SAGE III

Inclined Flight of Opportunity CERES, EOSP, NSCAT-2, and SAGE III

Other Flight of Opportunity ACRIM, SOLSTICE

Table 6. Instruments for Early 21st Century

| NASA AM Cluster | CERES, MISR, MODIS-N | NASA PM Cluster | CERES, AIRS, HIRS, MODIS-N |
| Free Flyers | SeaWIFS-2, TOPEX/POSEIDON-2, TRMM-2 |
| Polar Flight of Opportunity | EOSM, HIWLS, MOPITT, NSCAT-2, SAGE III |
| Inclined Flight of Opportunity | CERES, EOSP, NSCAT-2, SAGE III |
| Other Flight of Opportunity | ACRIM, SOLSTICE |

Summary

The recommended EOS platforms and instruments 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. While the program, as proposed, will advance our understanding of climatic processes and change, it is neither sufficiently extensive to solve all identified climate problems nor is its implementation without some risk.

Cost savings result from the following changes: reimplementation of the program as it was proposed a year ago:

1. Fewer instruments and changes in launch schedules have affected both the size and development pace of EOSDIS.
2. Several instruments have been eliminated from the program.
3. Some instruments have been deferred until later in the mission, thus reducing the number of instrument copies. Similarly, some instruments should be moved to the operational NASA DIS-N series.
4. Increased reliance has been placed on international partners for critical measurements, again reducing the number of NASA-provided instruments or instrument copies or platforms.

What Has Been Lost

- The removal of instruments to measure stratospheric wind and solar-terrestrial fields and the cancellation of either MLS or SAFIRE will lose characterization of the stratosphere during a period of rapid anthropogenic chemical change.
- The deferral into the 21st century of sensors that collect complete spectral information—visible spectral coverage by MODIS-T and HIWLS, shortwave infrared coverage by HIRS, and thermal infrared interferometry by TES—will impair our study of the exchange of trace gases between the ocean, land, and atmosphere, and increases the chance that observations of unanticipated environmental problems will be missed.
- Descoping of GLS, removing target upper tropospheric mesoscale processes that precede and follow earthquakes and volcanic eruptions. This capability should be pursued through development in other NASA programs, as well as with the collaboration with other agencies or international partners.
- Determination of whether the pole ice sheets are growing or shrinking is deferred until the 21st century. Changes in ice sheet volume are indicators of multi-year climate change, and the monitoring of ice sheets is needed to understand and predict sea level change.

What Is at Risk

- Continuity of data is at risk: scatterometer data if NSCAT-2 is not selected for ADEOS-2; continuity of ocean color data without extension of SeaWIFS purchase: visibility of ocean topography data without TOPEX/POSEIDON follow-on; long data gap in ERBE-quality radiation budget measurements if SCARABE (France/USSR) or DOE instruments are not available before the launch of TRMM; and continuity of precise measurements of the ozone profile without flight of SAGE III on satellites in mid-inclination orbits.
- Global measurements of the tropospheric wind field and the determination of the transport of moisture and trace gases are a risk without the flight of LAWS. Without a
multi-frequency synthetic aperture radar, we miss global studies of structural vegetation characteristics, such as biomass, along with soil moisture and snow properties. Finally, we have not been able to identify flights of opportunity for solar irradiance measurements made by ACRIM and SOLSTICE.

References

Ocean Bottom Seismometer Facilities Available


The Office of Naval Research, together with Scripps Institution of Oceanography, University of Washington, Massachusetts Institute of Technology, and Woods Hole Oceanographic Institution, is pleased to announce the formation of two national Ocean Bottom Seismometer (OBS) facilities. Recent advances in marine seismic and acoustic research, including whole Earth tomography, seismic refraction tomography, detailed passive seismology, high-resolution seismic refraction, and marine ambient noise studies, require a suite of identical calibrated seafloor instruments for analysis of array data collected by OBS capable of sustained deployment periods. Such instruments require a recording capability that is substantially improved in terms of bandwidth, recording capability, fidelity, and deployment duration over that possible just a few years ago.

Recognizing a deficiency in existing instrumentation, in 1987 ONR embarked on an effort to fund the design and construction of a new generation of OBS. Thirty-one instruments are now available for general use, and we encourage investigators to use the national OBS facilities as an effective means of acquiring state-of-the-art ocean floor seismic data. The two OBS facilities will be managed and operated on a joint institutional basis by WHOI and MIT, and SIO and UW, respectively. While the instruments will be managed and operated by the OBS facilities, ownership of the OBS will be retained by ONR.

Instrument Technical Specifications
Each OBS consists of an external sensor package, separate electronics and recording packages, and an exterior frame/anchor assembly (Figure 1). A summary of the pertinent instrument capabilities include:
- Gimbaled Mark Products 4AC triaxial 1-Hz geophones with calibration coils, with a frequency bandwidth between 55 mHz and 64 Hz.
- Differential pressure gauge sensor [Cox et al., 1984], with a response of 5 mHz to 30 Hz. Standard Ocean & Atmospheric Science, Inc. E-2PD hydrophones also can be provided, with a frequency response from 1 Hz to 5 kHz.
- Six channels are available for recording at up to 256 samples per second.
- 16-bit A/D converter, plus 36-dB fast gain ranging under software control.
- 400-Mbyte recording capacity using optical disks with an SCSI interface. Future upgrades in recording capacity are envisioned.
- 60-day deployment capability.
- Seacan clock, with less than 10-ms drift per year at 0°C.
- 6800 m (10,000 psi) rated depth capability.
- Independent commercial (EG&G Model 8242) acoustic releases and deck units, modified to enable acoustic in situ diagnostics.
- Radio and flashing light recovery aids.
- SAIL (Serial ASCII Interface Loop) interface allowing for simultaneous checkout of multiple instruments aboard ship.
- Glass spheres provide sufficient buoyancy for recovery even if a pressure vessel floods.

Additional technical details of the OBS can be found in the work of Sauster et al. [1990]. An example of data collected by these new OBS is shown in Figure 2, depicting a small magnitude local earthquake recorded on the East Pacific Rise.

The National OBS Facilities
The national OBS facility consortia can provide pre-cruise planning, at-sea technical support, data transcription and archiving, and quality control of the recovered data. Depending on the user's needs and capabilities, some or all of the shore-based and at-sea technical support can be provided. Preliminary estimates of the costs for a dozen OBS range from $70,000 to $130,000 for a

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One of the new generation of ocean bottom seismometers is being lowered into the ocean for a deployment off the east coast of the United States. Each OBS is approximately 2 m long by 1 m high and wide. Eight glass spheres, covered with yellow and orange "hard hats" provide sufficient buoyancy for recovery. The small sphere mounted at an angle at the upper right of the OBS is the external sensor package, consisting of a gimballed triaxial 1-Hz geophone package. The horizontal cylinder near the bottom of the OBS frame contains the acquisition electronics, while another cylinder (not seen at the bottom rear) contains the recording electronics and batteries. Two flashing lights and a single radio beacon are also visible at the top of the frame surrounding the hoisting ball.