PEER-REVIEWED ARTICLE

Earth Science Data for All: EOS and the EOS Data and Information System

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Introduction

The NASA Earth Observing System (EOS) program addresses significant science questions, the answers to which bear directly on vitally important environmental policy issues. The goals of EOS are to obtain a scientific understanding of the Earth as a system and to develop the capability to predict environmental changes that may result from human activities. The entire suite of EOS-related endeavors — a comprehensive space-based observing system, a data and information system, and a multidisciplinary and interdisciplinary scientific research program that uses the data and information to improve our understanding of humankind's impact on climate and the Earth's environment — is a science and technology program in support of policy and resources decision-making. The observing portion of the program will acquire high-priority new measurements to combine with critical historical and contemporary data sets. The EOS Data and Information System (EOSDIS) will embody the state-of-the-art in information systems components and system design, and will make use of the most forward-looking information processing and management tools. It is an evolutionary system, beginning with an initial capability in 1994, and adding increasing functionality and capacity to accommodate data taken from EOS instruments as they are launched. Design precepts are based on modularity to allow easy infusion of the newest technologies as they emerge, and to allow the ability to adapt to maturing user requirements. To understand the significance of EOS and EOSDIS to the science community, we must understand the philosophy, plans, and reality of this exciting program.

Global change, ozone depletion, deforestation/desertification and loss of biodiversity, acid rain deposition, and the greenhouse effect are all phrases associated with a cataclysmic future for life on Earth. They have rooted themselves in the public consciousness lately, with little in the way of real understanding of what they mean. Take, for example, the phrase *global change,* thought by many to mean that humans are responsible for changes in the Earth system. Global change has been with this planet since its formation some 4.5 billion years ago, long before humankind evolved. The Earth is a very dynamic system; it has changed, is changing, and will continue to change even with no forcing by humans. It has weather, volcanism, meteoritic impacts, and more. As for the greenhouse effect, the Earth's surface would be 33°C cooler today were it not for a greenhouse effect; hence, there would likely be no life on Earth were it not for a greenhouse effect that began many millions of years ago.

What is of concern is that the rate of some of those changes appears to be increasing, and there are data which at least suggest, if not absolutely indict, human activity as a source of that rate increase. Increasing deforestation, polar (and now, perhaps, mid-latitude) ozone depletion, and global warming may be the result of anthropogenic activity (Plate 1). Recent climate models predict as much as a 5°C rise in temperature by the end of the next century in response to the build-up of greenhouse gases in our atmosphere brought about by human activities.

Mission to Planet Earth and the Earth Observing System

We are only just beginning to understand how these changes will affect the Earth as a whole; international programs have been established to answer the many science questions that have arisen about how the Earth system works. In the U.S., 18 departments and agencies of the federal government are involved in the U.S. Global Change Research Program (USGCRP), including NASA's multi-component Mission To Planet Earth (MTPE) and its centerpiece, the Earth Observing System.

The USGCRP and the Intergovernmental Panel on Climate Change identified uncertainties which are key to understanding global climate change and which must be addressed. Supplementing these uncertainties with studies by other agencies and EOS investigators, MTPE and EOS have derived a set of seven overall themes which require further study. They are, in decreasing priority order, the role of clouds, radiation, water vapor, and precipitation; the productivity of the oceans, their circulation, and air-sea exchange; the sources and sinks of greenhouse gases, and their atmospheric transformations; changes in terrestrial carbon energy and water cycles; changes in land use and land cover; the role of the polar ice sheets, and sea level; the coupling of ozone chemistry with climate and the biosphere; and the role of volcanoes in climate change.

To pursue these themes, the EOS Program will develop highly sophisticated instruments and a massive data system. The EOS Program consists of

- a long-term repeating series of low-Earth-orbiting satellites with highly sensitive calibrated instruments, designed to pro-

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Plate 1. Human activity plays a major role in global change. Some emissions from automobiles and factories pollute the air, sending chemicals into the atmosphere, some chemicals contribute to the depletion of the ozone layer, allowing UV radiation to penetrate to the surface; in Brazil, developers clear rain forests, thereby destroying a possibly significant carbon sink. (Photo credits: Bus exhaust and factory smoke, S. C. Delaney/U.S. EPA.)

vide systematic, long-term global observations of the terrasphere, biosphere, cryosphere, atmosphere, and hydrosphere;

- a state-of-the-art data and information system to provide rapid and easy access to data in usable and understandable form by geographically dispersed users; and
- an interdisciplinary scientific research program to transform satellite observations of the Earth's atmosphere, oceans, and land surface into an understanding of the Earth as a system, and to develop and apply a predictive capability.

EOS is based on a succession of multi-instrument intermediate-sized spacecraft and individual smaller satellites to be launched over the next two decades. The first mission, EOS AM-1, scheduled for launch in June 1998, is comprised of five instruments. The Moderate Resolution Imaging Spectroradiometer (MODIS): the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), developed by Japan; the Measurement of Pollution in the Troposphere instrument (MOPITT), developed by Canada; the Clouds and the Earth's Radiant Energy System instrument (CERES); and the Multiangle Imaging Spectroradiometer (MISR). Together, these instruments will obtain detailed information on ocean productivity, clouds, and radiation and the land surface over a much wider range of wavelengths and with higher spatial resolution than has been done previously. This joint U.S.-Canada-Japan effort will provide significant clues towards defining the Earth system as an integrated whole, rather than as an assembly of independent processes.

There are currently a total of nine missions, including EOS-AM, that will be flown as part of Mission to Planet Earth (refer to Figure 3). EOS COLOR will be launched later in 1998 and will study ocean color and productivity. COLOR will consist of a second-generation sensor based on both the Nimbus-7 Coastal Zone Color Scanner (CZCS) and the Sea-Viewing Wide Field Sensor (SeaWiFS). As a follow-on to the SeaStar/SeaWiFS mission in 1994, COLOR will provide more data on the role of oceans in the global carbon cycle, the fluxes of trace gases at the air-sea interface, and ocean primary productivity. COLOR will also be a "data buy" mission, meaning that NASA will contract for the purchase of data from a commercial mission rather than contract for the development of the spacecraft and instrument.

Two missions, AERO-1 and EOS PM-1, are scheduled for launch in 2000. AERO-1 will provide data on the role of stratospheric aerosols and ozone, as well as upper tropospheric water vapor in the environment, and EOS PM-1 will study clouds, precipitation, and the Earth's radiative balance; terrestrial snow and ice; sea-surface temperature; and atmospheric temperature. Currently, the AERO series consists of the Stratospheric Aerosol and Gas Experiment III (SAGE III). AERO follow-on flights are scheduled for 2003, 2006, 2009, and 2012. Together, these missions will provide an important long-term baseline of parameters for radiative and atmospheric chemistry models. EOS PM-1, as well as the entire PM series, will have some of the same capabilities as the AM series with added temperature sounding capability. The PM spacecraft will have an afternoon equatorial crossing time, allowing contrasts and comparisons to be made of cloud and atmospheric properties measured by the PM instruments with those measured by the AM instruments. MODIS and CERES are scheduled to fly on both the AM and PM series of spacecraft. The PM series is scheduled to be launched every five years from 2000 through 2010.

In 2002, ALT-1 and CHEM-1 will be launched. ALT instruments will provide measurements of sea ice and glacier surface topography, cloud heights, and sea surface topography. CHEM will study atmospheric chemical species and their transformations, focused primarily on stratospheric ozone concentrations. The ALT series, to be launched in 2002, 2007, and 2012, will continue the work of TOPEX/Poseidon through high-precision altimetry measurements of ocean topography. CHEM, which is based in part on the success of the Upper Atmosphere Research Satellite (UARS) and Nimbus-7 instruments, will have follow-on missions in 2007 and 2012.

EOS does not represent the entire spaceflight portion of MTPE. The MTPE Program also contains a set of Earth Probes which will address themselves to other aspects of Earth system science. Earth Probes are individual satellites, usually carrying only a few instruments, that are dedicated to short-term, single-purpose observations. UARS, launched in 1991, was an Earth Probe designed to improve knowledge of the atmosphere above the troposphere, with primary focus on the chemistry, dynamics, and energy balance of the stratosphere and mesosphere. Other probes include instruments such as the Total Ozone Mapping Spectrometer (TOMS), which will provide measurements of the total ozone content of the Earth's atmosphere, and SeaWiFS, intended to make global measurements of ocean color as a follow-on to CZCS. The joint U.S.-French TOPEX/Poseidon mission is already making accurate measurements of sea-level processes. The NASA Scatterometer (NSCAT) is scheduled to fly on the Japanese Advanced Earth Observing Satellite (ADEOS) in 1996, and SeaWinds, a follow-on to NSCAT, is expected to fly on ADEOS II in 1999. These sensors are designed to provide global measurements of ocean wind vectors in the range of 3 to 30 m/s with an accuracy of the larger of 2 m/s or 10 percent in speed and 20° RMS in direction, at a spatial resolution of 50 km. The Tropical Rainfall Measuring Mission (TRMM) is a joint effort between NASA and Japan to measure precipitation occurring over the tropics and subtropics.

These missions, and many more, will provide important information necessary to support a wide variety of interdisciplinary science investigations. Studies of the hydrologic component of the Earth's climate will need data from most of the AM-1 instruments, as well as from the Multifrequency Imaging Microwave Radiometer on board the PM spacecraft. Investigations of the global carbon cycle will involve analysis of data from both pre-EOS and EOS-era instruments. Other interdisciplinary projects include the studies of biosphere-atmosphere interactions, the global assessment of active volcanism, and climate processes over the ocean.

An Earth observing program of this magnitude, and with these and other varied instruments and investigations, will generate large amounts of data on a continual basis, requiring the development of more advanced methods of data management, reduction, and handling. This aspect of EOS will be handled by EOSDIS. The goals of the EOSDIS are to command and control the spacecraft and instruments; and to ingest, process, store, retrieve, and distribute Earth observation data obtained using EOS and other satellite- and ground-based activities.

EOSDIS will make Earth remote sensing data available to a broad range of interested communities. EOSDIS must meet the requirements of many potential data customers, including Earth scientists, policy makers, resource planners, commercial and industrial users, and educators.

Technical Description of EOSDIS Capabilities and Services

EOSDIS is a geographically distributed system. Its multiple data processing and storage components are placed at centers having exceptional Earth sciences expertise, extensive physical and technical resources capable of providing the requisite level of service to the user community, and a long-term institutional commitment to participate in Global Change research. EOSDIS will not only store and manage the data from the EOS spacecraft, but will also make accessible and distribute Earth observation data from other sources, including NASA Earth Probe missions, scientific field campaigns, and selected data related to the EOS mission from other federal agencies. The key components of the science data processing segment of EOSDIS and their interrelationships, which are described in detail below, are pictured in Figure 1.

The architecture chosen for EOSDIS combines the strengths of a distributed data archive (i.e., data maintained by organizations with information management expertise in the associated science discipline, resiliency and robustness, and distribution of user load) with the advantages of a common design (single user interface for data location and access across multiple data centers, data center systems based on an incrementally extendible configuration of common building blocks to minimize development cost, and standard data structures to facilitate integration of observations for interdisciplinary studies).

Distributed Active Archive Centers (DAACs) are located at eight sites throughout the United States, and are identified by science discipline in Table 1. These sites are responsible for processing, archiving, and distributing EOS and related data and for providing a full range of user support. These institutions ensure that data will be available indefinitely in an easily accessible form. Acting in concert, DAACs will support global change researchers whose needs cross traditional discipline boundaries, while continuing to support the particular needs of the DAAC-assigned scientific discipline community. Each EOS DAAC contains functional elements that include a Product Generation System, a Data Archive and Distribution System, and an Information Management System.

- The *Product Generation System (PGS)* performs data processing functions, including routine generation of standard products, quick-look products, metadata, and browse data sets. Reprocessing of data, when called for to implement improved instrument calibration or geophysical parameter retrieval algorithms, and retrospective production of new standard products, is also done here.
- The *Data Archive and Distribution System (DADS)* is responsible for managing and storing EOS data and information, including EOS standard data products, ancillary and correlative data, metadata, command histories, algorithms, and documentation. Data will be distributed from the DADS to EOS scientists, other EOS facilities, and other research users electronically via networks (see below) or on high-density storage media (e.g., CD-ROMs, tape, etc.), depending on the size of the requested data set.
- The *Information Management System (IMS)* is the part of EOSDIS that will be seen by the users. It provides information about EOSDIS data holdings on a 24-hour basis; provides pointers to external archives with which EOSDIS interoperates;

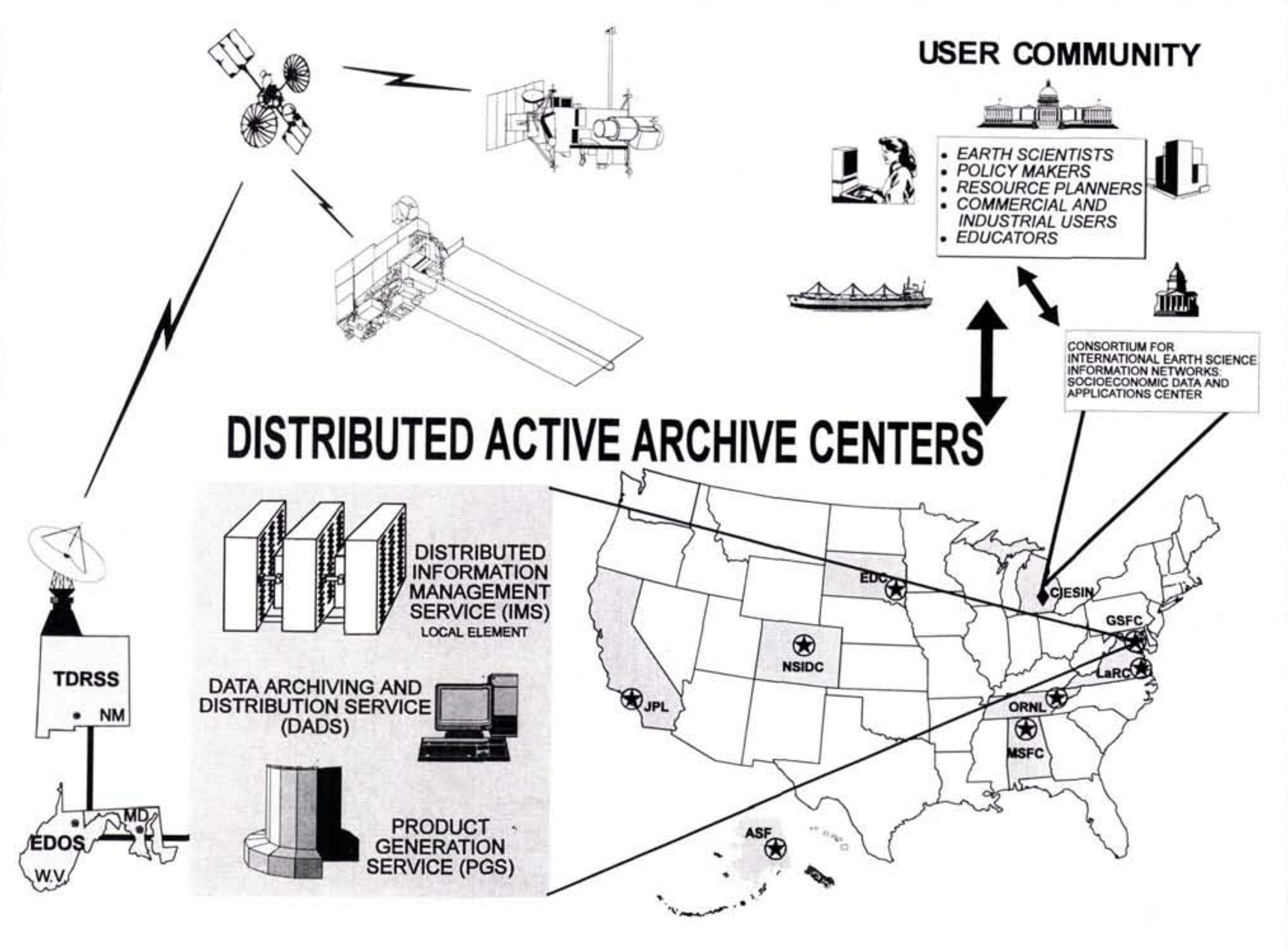

Figure 1. EOSDIS Architecture

accepts user orders for EOS and other Earth science data holdings; provides information about future data acquisition and processing schedules; accepts and forwards data acquisition and processing requests; and maintains information on system status, management, and coordination. While each DAAC will have its own resident IMS, EOSDIS users across the system will have the same view of the EOSDIS data holdings and capabilities, regardless of where they are located or which DAAC they access (Figure 2).

The Consortium for International Earth Science Information Networks (CIESIN) provides a *Socioeconomic Data and Applications Center* within EOSDIS. It supports the analysis of human dimensions of global change, and provides access to statistical databases on human activity to support correlative analyses with Earth science data.

Connectivity to EOSDIS will be accomplished using any of several *networks*, including the NASA Science Internet (NSI) and its connections to the National Science Foundation Internet. Full use of the National Research and Education Network (NREN) will occur as NREN is developed. The NSI network connections have sufficient bandwidth to allow rapid access to data holdings and to permit data transport of reasonably sized data requests.

Other elements of EOSDIS include the EOS Operations Center, International Partner Operations Centers, the System Management Center, Instrument Control Facilities, Instru-

Table 1. Distributed Active Archive Centers. DAAC locations are shown in Figure 1.

DAAC	Discipline
Goddard Space Flight Center (GSFC)	Climate, Meteorology, Ocean Biology
Langley Research Center (LaRC)	Clouds, Radiation, Aerosols, Tropospheric Chemistry
EROS Data Center (EDC)	Land Processes
University of Alaska Alaska SAR Facility (ASF)	SAR Imagery of Ice, Snow, Sea Surface
University of Colorado National Snow and Ice Data Center (NSIDC)	Polar Oceans and Ice
Jet Propulsion Laboratory (JPL)	Physical Oceanography
Marshall Space Flight Center (MSFC)	Hydrologic Cycle
Oak Ridge National Laboratory (ORNL)	Biogeochemical Cycles and Field Campaign Data

ment Support Terminals, Field Support Terminals, and Science Computing Facilities. These components deal more with management of EOSDIS and with the control of the spacecraft and its instrumentation than with the data themselves, and so will not be discussed in this paper.

Key features of EOSDIS include the following:

- Users will be able to search for data across all DAACs from a single interface;
- From the same interface, users may place requests for data from all DAACs without having to contact the DAACs individually; and
- EOSDIS will expand its capacity to facilitate ingesting, processing, archiving, and distributing the large volumes of data from EOS instruments as they are deployed.

The data in the EOSDIS will be available for on-line browsing through access to the Information Management System, a facility that will allow customers to peruse the entire library of data products accessible through EOSDIS, including data stored on non-EOSDIS systems but which have relevance to EOS data sets. The Science Processing Database (SPDB) is also on-line. Located at NASA's Goddard Space Flight Center, the SPDB is an interactive, on-line system that provides updated information about the EOS project, including information on instruments, investigators, output data products, input requirements, retrieval algorithms, and Version 0 data sets to be archived at the DAACs.

New technologies will allow customers to find data sets from multiple instruments, multiple missions, and multiple sources with great ease. Data customers will not be burdened with determining where their particular data of interest are located. In response to users' queries, EOSDIS will seek out and present data from all the Centers, and make them available at the users' workstations. Rather than requiring a user to go through several manual request-receive-assess processes, potentially dealing with several data centers, to locate observations of a phenomenon or region of interest, EOSDIS will enable science users to locate, browse, and order data interactively. To satisfy the immense data storage, access, and retrieval aspects of EOSDIS necessary to support this ease-of-access will require a complex system architecture with hierarchically organized high performance disk farms and high capacity archive systems. An advanced information management system for organizing and rapidly searching large inventories at multiple sites will also be required.

EOSDIS Data Holdings

The data to be accessible through EOSDIS covers the vast range of Earth system science, including atmospheric chemistry, humidity and temperature profiles, vegetation indices, ground cover characteristics, phytoplankton productivity, wind vectors, digital elevation models, snow and ice distribution and characteristics, soil and mineral characteristics, and more, at spectral and spatial resolutions and coverage heretofore unattainable.

High-quality standard calibrated data products provided by EOSDIS will be essential to distinguish between natural and human-induced variations of the environment and will give the community access to independent measurements to validate and drive models of processes on local, regional, and global scales.

EOSDIS will contain data from existing data sets such as the CZCS, Advanced Very High Resolution Radiometer (AVHRR), the Geostationary Operational Environmental Satellite (GOES), Special Sensor Microwave Imager (SSM/I), and Synthetic Aperture Radar (SAR). Several of these data sets are being used to develop a working prototype withoperational elements of EOSDIS, called Version 0 (Figure 3).

Existing data sets from Earth observing spacecraft are being used by EOS to establish the Pathfinder data sets. These were instituted in response to the immediate need for access to large space-based remote-sensing data sets prior to the availability of EOS data. In order for a data set to be included in the Pathfinder Program, these criteria are considered important; stable calibration of the raw data should be attainable, and, when data from multiple instruments are involved, consistent intercalibration among instruments in a series should be possible. In most cases, the data archive should be able to transfer the data to a more accessible medium. In 1990, Pathfinder data sets from NOAA AVHRR, the TIROS Operational Vertical Sounder, and GOES were generated from existing data sets. In 1991, the SSM/I data sets were added to the list; in 1992, selected Landsat Multispectral Scanner and Thematic Mapper data, as well as Nimbus-7 Scanning Multispectral Microwave Radiometer data were added. Other existing data sets are under currently under evaluation. All data sets in the Pathfinder series will be treated as new data sets and will be accessible from the EOSDIS DAACs.

Data Policies

Professionals in all fields of endeavor who have need for or use remotely sensed or correlative *in situ* data pertaining to Earth system processes will be able to access data holdings easily and inexpensively through new policies being put into

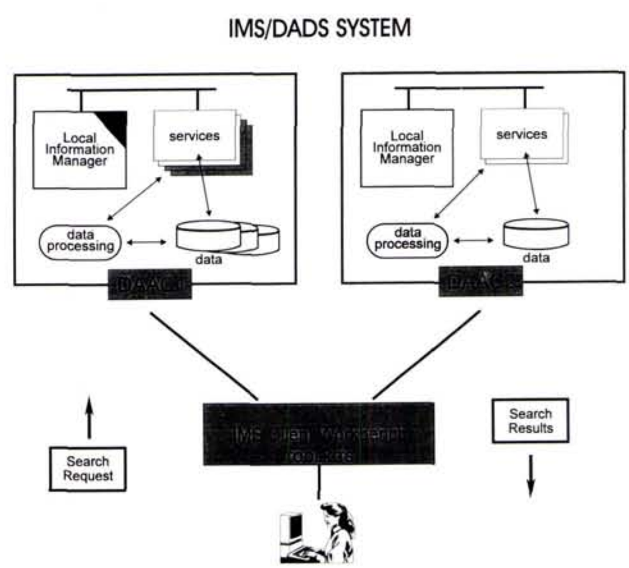

Figure 2. Providing science users with interactive access to EOS data will require an advanced information management/archive system.

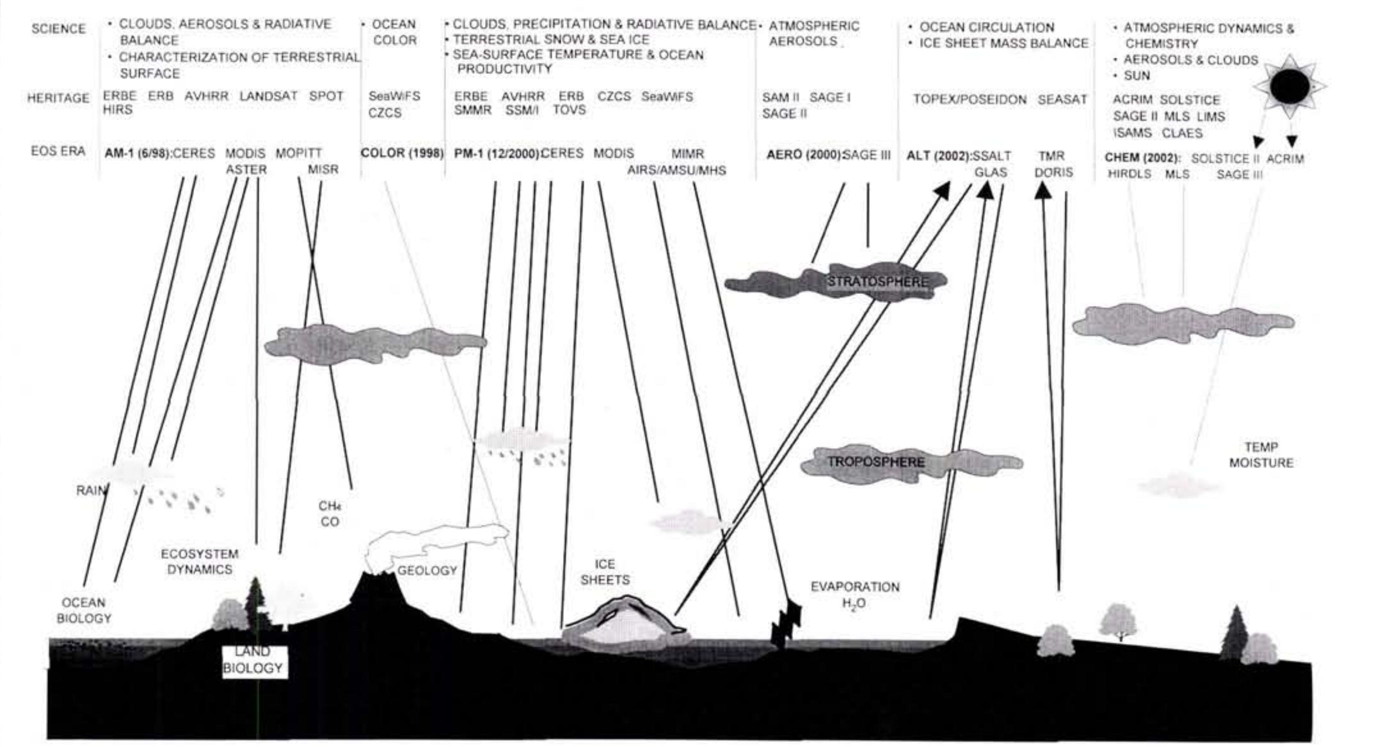

Figure 3. EOSDIS will provide users access to EOS-era data and heritage data sets of various Earth systems over long time scales.

place with the advent of EOSDIS. For example, NASA will make EOS data products openly available to researchers without a period of exclusive access. Commercial (and other) users will no longer have to wait for periods of proprietary access to data to expire before being able to use those data. In addition, users will pay only for the marginal cost of reproduction. The days of expensive, inconveniently accessible, and sometimes limited data holdings will end. Considerable thought has gone into developing data policies that will make availability of the data as inexpensive and rapid to the end-user as possible. To that end, the following policies have been adopted:

- Following the post-launch checkout period, Level 0 data will be available. Level 1 data will be ready within 24 hours after Level 0 data are available. Levels 2 and 3 standard products will be made available within 24 hours after receipt of the required input data. These higher level products will be archived.
- EOS data and products will be available to *all* users immediately upon their generation; *there will be no period of exclusive access.*
- All data requests for approved research, and non-commercial operational and applications demonstration purposes, will incur a modest charge consistent with the actual marginal costs of filling the request. This system will ensure reasonable allocation of EOSDIS resources, while not discouraging full use of EOS data. Data will be provided for other uses, including commercial activities, on the same time scales and at non-discriminatory prices and terms to be established by the relevant instrument provider and platform operator.
- EOSDIS will include and make available information about the data, such as quality assessments, supporting literature references, and catalog and directory entries.

Potential Applications and Benefits of EOS Data

The inexpensive and easy access to multispectral data at several spatial and spectral resolutions will have wide-ranging consequences for professionals in the public and commercial sectors. We can expect that these data might assist farmers to plan crop care schedules, allow land-use planners to route thoroughfares, and provide foresters and land-use managers with information to plan their use of natural resources. Students and teachers will be able to ask questions about the Earth system and its components, and be able to receive the data they need to answer those questions.

The details of EOS and EOSDIS are myriad and complex, but a major design goal for EOSDIS is to make access to data as easy as possible, with the complexities to be made as invisible to the users of the system as is practicable. In order to demonstrate the ways in which users will use the capabilities being designed for EOSDIS, we now present a narrative description of one user's interaction with the system.

Using EOSDIS: A Sample User Scenario

It is July 1999. One of Alaska's active volcanoes, Mt. Spurr, had been rumbling since May and has just recently erupted. A Department of the Interior environmental engineer wants to know the effect of the recent eruption on a nearby wildlife refuge. Of particular interest is the extent of vegetation and wildlife habitat damage. She will need to provide information to the Fish and Wildlife Service about what to do to repair ecosystem damage to the area. Because the refuge is also a popular tourist attraction, there is also a need to predict the ecosystem's recovery time, because that will, in turn, reflect the area's economic recovery period for tourism.

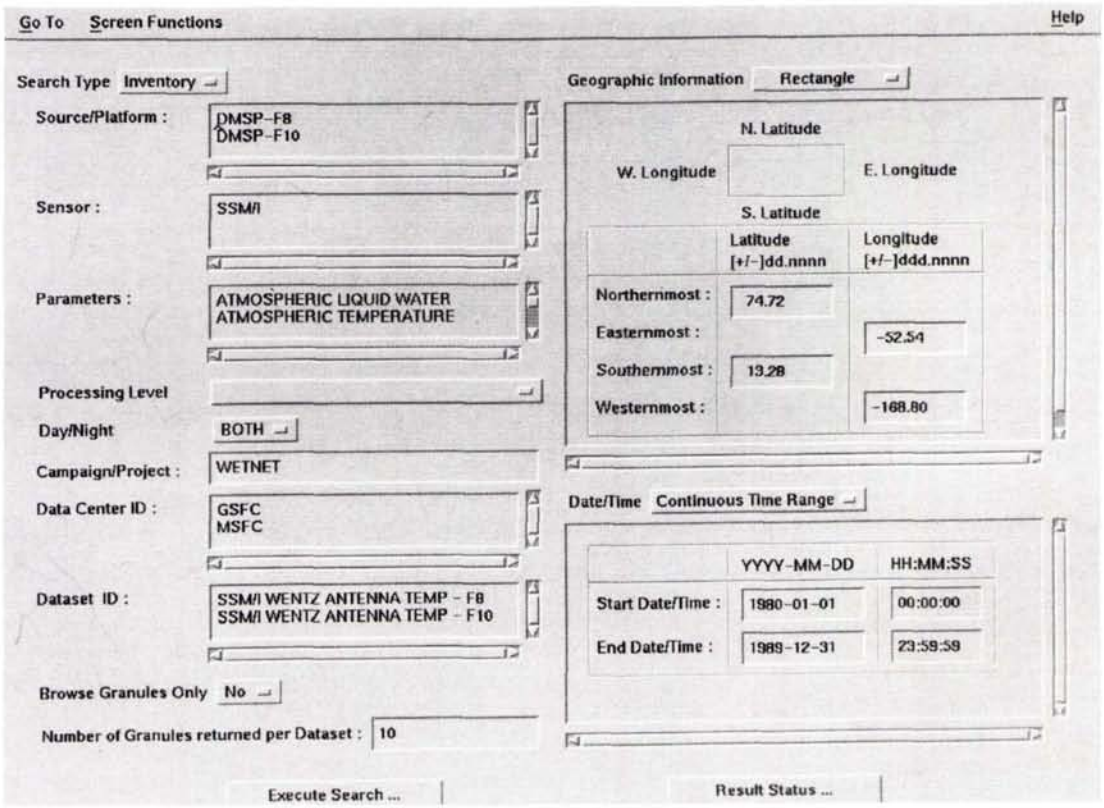

Figure 4. A typical IMS Search screen (VO). From this scree, the user may search for data based on parameters such as sensor type, measurement type, and geographic location.

The engineer wants a way to get maps quickly, so for the first attempt she uses her modem to call the EOSDIS Information Management System (IMS), access to which has previously been arranged. She finds that menus of instruments and geophysical parameters, map-making subroutines, database lists of Earth science-related publications, and many other useful tools are all included in the system. There is also an extensive help file, along with information on how to contact a knowledgeable user services support person (Figure 4).

The instrument menu provides a brief description of each instrument on the EOS AM-1 platform, and its purpose, resolution, and rate of global coverage. She finds that ASTER and MODIS data fit her purposes quite well. She selects MODIS because it provides global coverage every two days, allowing her to obtain "before" and "after" images. ASTER measurements will give her excellent resolution and will provide stereo elevation maps of the area, allowing her to determine the extent of changes to the volcano's cone.

After determining which instrument data she wants, the engineer selects the appropriate menu options to isolate the correct region of Alaska. She also selects pre-eruption data for the same area obtained by both instruments for comparison purposes. She switches to the visualization tools and begins choosing options to create custom-made images. After 30 minutes of work, she downloads the data to her computer.

In the course of her browsing, she comes across the online archive of research results. One of the subjects catches her eye — recovery rates of vegetation after volcanic eruptions. She discovers that the researcher is in Maine, obtains an E-mail address, and ends her first session by sending correspondence to him. She is impressed that this archive is almost as useful as the data archive. She was able to scan a list of subjects and get relevant titles in a matter of minutes. This work used to take an entire afternoon or more at a local university library (Figure 5).

In a matter of hours, the researcher responds, and tells her of other data available, possibly for her region, from NOAA AVHRR and Landsat Thematic Mapper (TM). In her next session on the IMS, the environmental engineer finds a large number of data sets from both of those satellites, some already processed and available as images and some as raw data. Using the mapping tools, she determines that the AVHRR and Landsat images are valuable for comparison studies of the aftermath and recovery rates of the same area after past storms. Knowing previous ecosystem recovery rates for the park allows her to make a much more accurate estimate for this storm. She also finds EOS COLOR mission images she will consider using. The data sets involved in making these maps are too large to be efficiently downloaded to her computer, though. She places a request to have NOAA AVHRR images of temperature and vegetation index sent to her on 8-mm tape. She will produce the map using her own copy of a

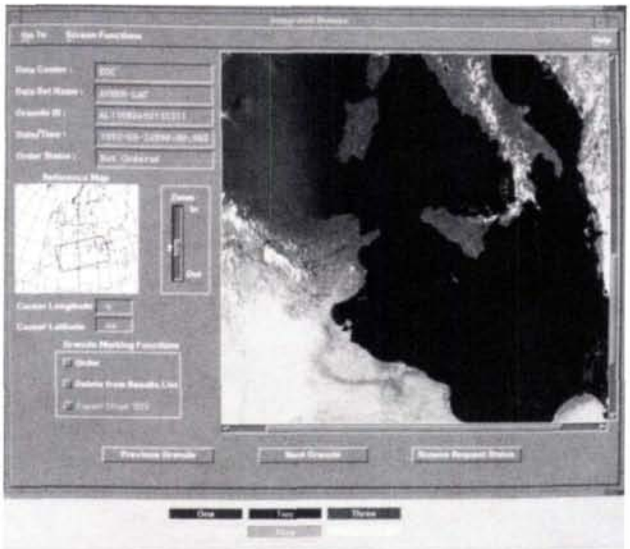

Figure 5. IMS users may select any region of the globe to obtain data from that area, rather than have to sift through data to find the desired geographic location.

commercial image processing program, which can take advantage of the standardized data format used for EOSDIS data. Within three days, the tape is on her desk.

While working with the AVHRR data, she discovers that the false-color map seems to show temperature fluctuations over locations as little as one km apart. The fluctuations could be due to cloud cover. Comparison with MODIS infrared cloud images shows cloud cover patterns which seem to confirm her suspicions. She determines that she needs more image processing capability than her software package offers, so she dials up the IMS once again and uses the tool kits provided. They enable her to overlay a grid on the image; change the contrast and brightness to highlight such features as cloud cover, and erosion; create false-color images to make vegetation more visible; smooth, rotate, or zoom the image; and much more.

After working with the instrument data for a while, the engineer decides she really only needs smaller subsets of some of these data sets. Already familiar with the mapping tools, she is able to select the data set and create the maps she needs rather quickly. The completed maps are then sent to her via E-mail. While she's logged on, she looks at the MODIS data. When she tries to pull up an image for the date in question, she gets an advisory message on the screen. The message tells her that there is a systematic 2 percent error in the calibration. Any images created with the calibrated data will produce biased results. The science team has implemented a new calibration scheme, and reprocessing is underway. In the meantime, she is given a choice between waiting and using the newer, correctly calibrated data for the same region, or going ahead and using the current data. She decides to wait until the calibration is improved so she can compare both old and new data during the same session. She sends a message to the system administrator asking that she be notified when the MODIS calibration problem has been solved. She receives a note a few minutes later confirming her request.

After this session, she realizes that she has had unlimited access to both recent and past data, obtained data from archives in South Dakota and Maryland, searched through research results from scientists around the world, and used data analysis and interpretation and information extraction tools, all with great speed and ease. Perhaps most importantly, though, all this has been done without ever leaving her workstation in Anchorage! Because the archives are available 24 hours a day, the engineer did not have to waste precious analysis time accommodating other schedules. A large portion of her image processing work was done during her sessions on the Information Management System, some of it in the middle of the night! Her supervisors are very happy when she announces her results only one week after she is given the assignment.

Earth Science Data for All

People in a wide variety of disciplines will be able to put EOS data to good use. Teachers, for example, can use EOSDIS in many ways: to explain geography using Landsat images, to teach image processing with MODIS images, or to give students a better understanding of their world with MOPITT or MODIS images. The high resolution maps that will be produced with ASTER data will be invaluable to cartographers. Instruments on the PM-1 platform will provide terrestrial sea ice information to help shipping lines plan their routes through ice floes. Knowing where to send the boats beforehand saves many resources, including money, fuel, and time. Foresters will be able to use MODIS to assess erosion and ecosystem damage caused by deforestation, and, by implication, to determine whether reforestation plans currently in use are effective. City, state, and federal government land-use policies could be enhanced or improved based on data from MODIS and ASTER. The list goes on.

EOSDIS Progress

The development of a distributed system to meet the data rates and volumes of the EOS program, and to support the interactive requests from a diverse Earth science research community for data search and retrieval, will require a fully integrated system design. An EOSDIS Core System (ECS) was conceived to provide the underlying extendible architecture foundation and the common hardware and software building blocks to be used at the distributed data centers. Incremental releases of ECS will be integrated with data center unique elements, telemetry processing systems, and communications systems to form operational versions of EOSDIS. EOSDIS Version 1 will be implemented in steps over a two year time frame, beginning in 1995. Version 2, which will be implemented before the launch of the first EOS spacecraft in 1998, will contain full instrument and mission support functions and product generation capabilities. Each subsequent version of EOSDIS will build upon the previous one, adding user support and spacecraft support services as required. In parallel with the design and development process for ECS, a prototyping effort was initiated both to test design concepts and to provide an initial capability for researchers to transparently access existing data distributed across the data centers. This effort, called Version 0 (V0), is developing a prototype of the IMS, but with a significant difference. In Version 1 and subsequent versions, the IMS data archive functions will be developed as part of an overall integrated design, which will enable more flexibility and responsiveness for data search and access. The V0 IMS, on the other hand, has to work with the pre-existing database management systems and data structures at the DAACs by translating queries based on standard keyword definitions and a standard format into query structures for the different DAACs. Results of inventory searches from the different data centers are similarly translated into a common format for display to the science user. The V0 prototype is on schedule for use by Earth scientists in mid-1994. Capabilities for search by geophysical parameter, sensor, and spatial and temporal coverage transparently across seven DAACs are now seeing limited testing and use. Browse data for some data sets are available over the Internet, and initial functions for data set ordering, including network transfers of small data sets, are being implemented. Other components of EOSDIS are already available. Other data sets are accessible via the USGS Global Land Information System (GLIS), located at the EROS Data Center (EDC) in Sioux Falls, South Dakota. We should emphasize that data are already available to support such activities. The Pathfinder data sets, in place now, will be available for use through IMS Version 0 when it comes on line. However, the combination of the long-term, contiguous, calibrated data sets to be provided by the EOS-era instruments and the fully functional EOSDIS will enable investigators to ask more and farther-reaching questions than could be expected with pre-EOS-era data and utilities.

Conclusion

The long-term, contiguous data to be made available from EOS through EOSDIS will benefit not only Earth system science investigators, but will also reach land use planners, resource managers, governmental decision makers, and the commercial sector, as well. The tools to be made available through EOSDIS will make those data easily accessible at low cost, and will help us understand the processes our planet undergoes, and the effects of human activity upon those processes.

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Appendix I

Data Level Definitions:

- Level 0 Reconstructed unprocessed instrument/payload data at full resolution; any and all communications artifacts (e.g., synchronization frames, communications headers) removed.
- Level 1A Reconstructed unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters (i.e., platform ephemeris) computed and appended, but not applied, to the Level 0 data.
- Level 1B Level 1A data that have been processed to sensor units (not all instruments will have a Level 1B equivalent).
- Level 2 Derived geophysical variables at the same resolution and location as the Level 1 source data.
- Level 3 Variables mapped on uniform space-time grid scales, usually with some completeness and consistency.
- Level 4 Model output or results from analyses of lower level data (i.e., variables derived from multiple measurements).

Appendix II

If you would like more information about the Mission to Planet Earth Program, the Earth Observing System, or any missions mentioned in this article, please contact any of the following people:

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