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The Earth Science Enterprise Series

These articles discuss Earth's many dynamic processes and their interactions.

NASA's Earth Science Enterprise: *http://earth.nasa.gov*
NASA's Earth Observing System Project Science Office: *http://eos.nasa.gov*
NASA's Earth Observatory: *http://earthobservatory.nasa.gov*

An Overview of the Earth Science Enterprise

Introduction to ESE

Our Earth is unique among the planets with an abundance of water and highly diversified life. Its land, atmosphere, oceans, and all forms of life interact in many complex ways to form a complex Earth system. NASA provides a unique vantage point from space that is the only effective way to study global scale phenomena and to understand local, regional and global-scale changes in their larger context. The mission of NASA's Earth Science Enterprise (ESE) is to develop a scientific understanding of the Earth system and its response to natural and human-induced changes to enable improved prediction of climate, weather, and natural hazards for present and future generations. ESE has three major goals:

1) ***Science***: Observe, understand, and model the Earth system to learn how it is changing, and the consequences for life on Earth.
2) ***Applications***: Expand and accelerate the realization of economic and societal benefits from Earth science, information, and technology.
3) ***Technology***: Develop and adopt advanced technologies to enable mission success and serve national priorities.

ESE Research Strategy

ESE has mapped out its research priorities through 2010. The research strategy is designed to answer a fundamental question of societal importance:

> *How is the Earth changing and what are the consequences for life on Earth?*

In and of itself, this question is very difficult to answer, so NASA's ESE has come up with five more specific questions designed to look at different aspects of the broader question:

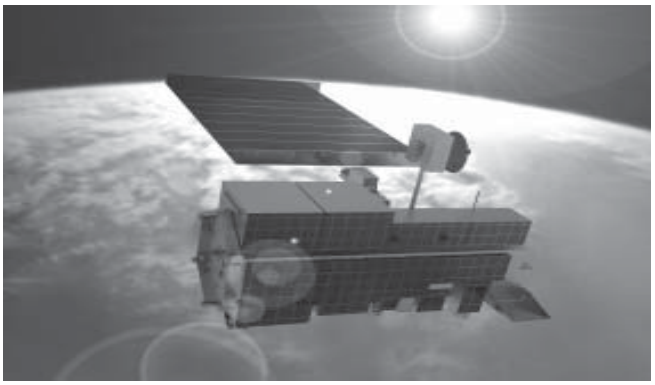
- ***Variability***: How is the global Earth system changing?
- ***Forcing***: What are the primary forcings of the Earth system?
- ***Response***: How does the Earth system respond to natural and human-induced changes?
- ***Consequence***: What are the consequences of change in the Earth system for human civilization?
- ***Prediction***: How well can we predict future changes to the Earth system?

Undergirding each of these are even more specific questions (totalling 23) that drive requirements for new research tasks and new remote sensing and *in situ* observations to be satisfied by satellite, suborbital and surface-based observing systems.

ESE Applications Strategy
Given the enormous practical utility of Earth remote sensing, ESE's Applications Program works to help Federal, State, local and tribal governments and private sector decision-makers adopt remotely sensed observations and Earth system models in their own decision support systems. The largest on-going example is the use of meteorological satellites in weather forecasting. Not far behind is the use of remote sensing to observe land cover and land use change. ESE provides the technology and scientific understanding to demonstrate these applications, which are then routinely performed by service provider organizations in government and industry.

The Applications Division seeks to bridge the gap between Earth science research results and stakeholders outside the research community who can utilize these results operationally and derive useful applications for society as a whole. To better accomplish this, the Applications Division has established the National Applications Initiative (NAI). Twelve applications have been selected that respond to national priorities and also demonstrate practical uses of NASA-sponsored observations from remote sensing systems and predictions from scientific research and modeling.

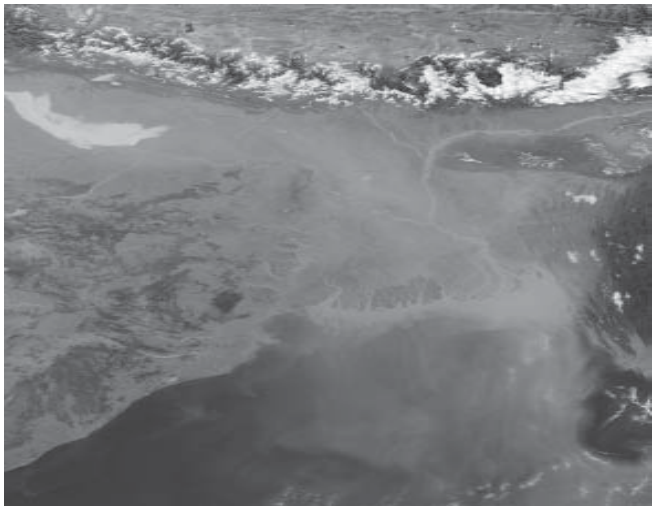
ESE Mission Programs
ESE's research and applications requirements for Earth observation are met through a slate of systematic, exploratory and technology demonstration/ operational precursor satellite programs, and a diversified suborbital science program of aircraft and balloons. Systematic measurement missions are those that supply long-term data records to determine variability and trends in parameters of known importance, such as atmospheric temperature and humidity, and vegetation cover. The more mature measurements become candidates for transition to operational systems, such as NOAA's meteorological satellites (which are currently built and launched by NASA). Exploratory measurement missions are those designed to probe poorly understood Earth system processes, such as the 3-D profile of aerosols in the atmosphere or the Earth's gravity field. Once these processes are understood, and their change over time is found to be important, they become candidates for future systematic measurement missions. Technology demonstration/operational precursor missions are intended to reduce the cost of today's measurements or make possible those of tomorrow. From 1999 through 2003, ESE has launched 14 successful missions, and plans 10 more through 2004.



This drawing depicts the Terra spacecraft in orbit. Terra is the flagship of the EOS Program and the instruments on board provide a wealth of new knowledge about the Earth System. The Aqua and Aura spacecraft are of a similar design.

The Earth Observing System (EOS) was created primarily to meet the need for systematic measurements, and is the largest component of the ESE. It aims to carry NASA's legacy of focused Earth Science measurements into a new era of comprehensive data sets, leading to an improved understanding of the Earth as a complete global system. EOS is managed by the Goddard Space Flight Center, including the Wallops Flight Facility, and receives important contributions from other NASA centers: Jet Propulsion Laboratory, Langley Research Center, Marshall Space Flight Center, and Stennis Space Center. In addition, NASA works in conjunction with many other partners from government, industry, academia, and with international space agencies.

Twelve missions are planned as part of the EOS program and already NASA has launched nine of these missions. Listed in chronological order these include Landsat-7, the Quik Scatterometer (QuikScat), Terra, the Active Cavity Radiometer Irradiance Monitor



This image was acquired on December 4, 2001 by the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard Terra. The image centers on Northern India. Pollution (the grayish haze) can be seen all along the southern edge of the snowcapped Himalayan Mountains to the north and streams southward to Bangladesh and the Bay of Bengal. Most of the aerosols are byproducts of human activities.

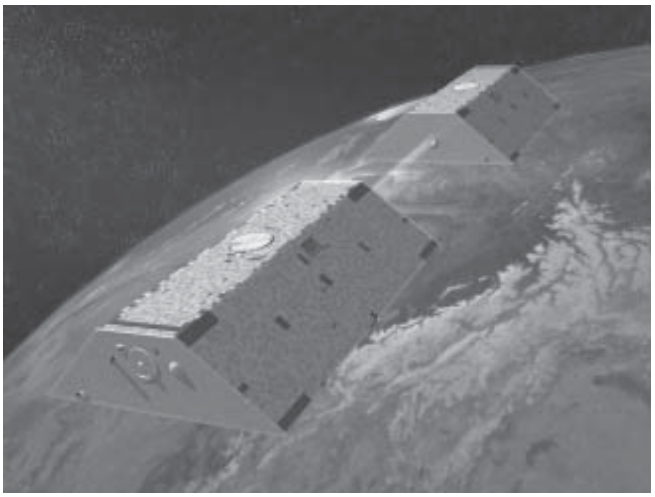
Satellite (ACRIMSAT), Jason-1, the Third Stratospheric Aerosol and Gas Experiment (SAGE III—Meteor 3M), Aqua, the Ice Clouds, and land Elevation Satellite (ICESat), and the Solar Radiance and Climate Experiment (SORCE).

The three major EOS missions are Terra, Aqua and Aura. Terra launched in December 1999 and is the flagship of the EOS program. It is a joint mission with Japan and Canada that carried five advanced instruments into orbit to study land and ocean surfaces, sea surface temperature, cloud patterns, small atmospheric particles called aerosols, and the balance of solar energy absorbed and reflected by Earth. In May 2002, Aqua joined Terra in orbit. Aqua carries a synergistic instrument payload designed to observe how moisture cycles between Earth's lithosphere (land), hydrosphere (water), atmosphere (air), and cryosphere (ice). Aura is scheduled to launch in 2004 and carry a suite of instruments that will study the complex chemistry of the atmosphere.

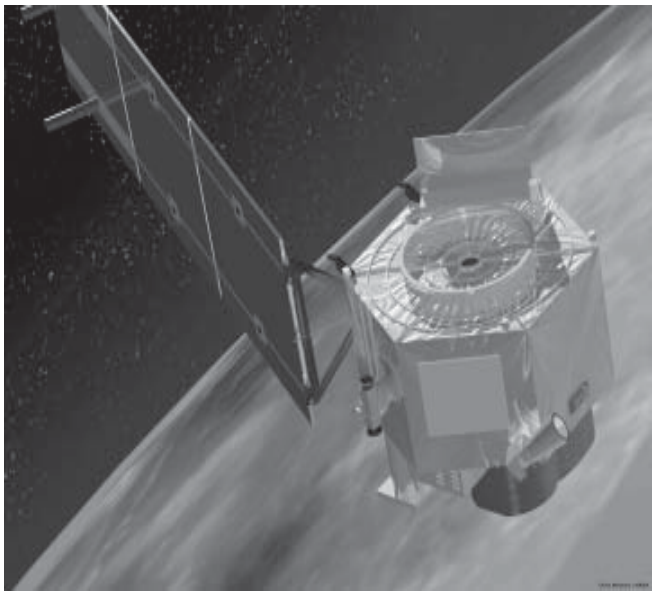
The two most recent EOS launches are SORCE and ICESat. SORCE launched in January 2003 and makes daily measurements of total solar irradiance between wavelengths of 1 nm and 2000 nm. ICESat also launched in January 2003 and measures precisely the elevations of Earth's ice sheets.

The Earth System Science Pathfinder (ESSP) program is the primary source of exploratory missions for ESE. These are smaller and cheaper missions designed to complement the main EOS missions and proposed by the scientific community to address specific research questions. They are developed and implemented on a faster schedule, competitively selected, and led from development through data distribution by a Principal Investigator.

The Gravity Recovery and Climate Experiment (GRACE) launched in March 2002 and is the first ESSP mission to fly. GRACE consists of two separate satellites in tandem orbit. A highly precise microwave ranging instrument measures infinitesimal changes in the distance between the two bodies to obtain the most precise measurements of the gravity field that have been achieved to date. Many scientific disciplines eagerly await advances that should derive from these data. A second launch in 2004 will deploy two more ESSP missions—CloudSat and CALIPSO. CloudSat is a satellite experiment designed to measure the vertical structure of clouds from space, which



GRACE is the first ESSP mission. It will obtain the most precise measurements of Earth's gravitational field that have ever been achieved. Improved resolution of the gravity field will lead to important advances in a number of disciplines that study the Earth's climate.

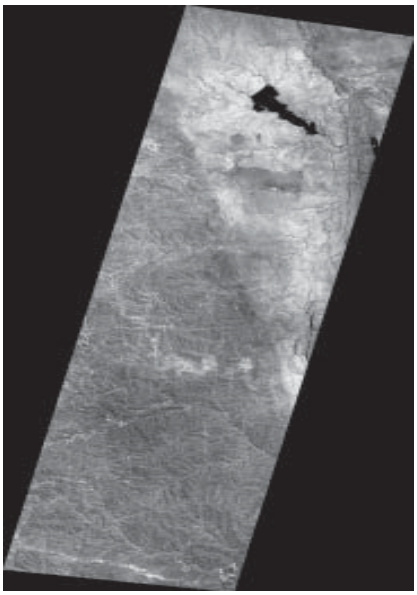


The drawing above depicts the EO-1 spacecraft in orbit. EO-1 is the first NMP launch and carries instruments intended to demonstrate new technologies and serve as a testbed to develop instrumentation for future NASA missions.

will contribute to better predictions of clouds and effects of clouds on Earth radiation. The Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observer (CALIPSO) will profile the atmosphere using lidar and provide a global set of data on aerosol and cloud properties, radiative fluxes, and atmospheric state. These two spacecraft will fly in formation with Aqua, Aura and a French mission called Polarization and Anisotropy of Reflectances for Atmospheric Science Coupled with Observations from a Lidar (PARASOL) as part of what is known as the A-Train formation. The resulting measurements will be synergistic—meaning the combined measurements give more information than the sum of the observations taken independently—and will greatly improve our ability to predict future climate change.

In 2007, two more ESSP missions will be launched. The Orbiting Carbon Observatory (OCO) will make global space-based observations of carbon dioxide concentrations, and Aquarius will study the salinity of the oceans from space and collect additional information on soil moisture over land. Originally selected as an ESSP mission, The Vegetation Canopy Lidar (VCL)—whose principal mission is the characterization of the three-dimensional structure of the Earth's forest canopy and a global reference data set of topographic heights and transects—is now being pursued as a technology demonstration. A decision is pending on whether to proceed with a satellite mission.

The New Millennium Program (NMP) is the principal source of technology demonstration/operational precursor missions for ESE. NMP serves as a testbed for the development of cutting edge technology for future Earth science instruments and spacecraft. The first NMP mission, Earth Observing-1 (EO-1), was launched in November 2000. EO-1 carries an Advanced Land Imager designed to continue the measurements made by the Landsat series at a much lower cost and using an instrument that is 4 to 5 times smaller than the Enhanced Thematic Mapper Plus (ETM+) instrument on Landsat. Meanwhile, the Hyperion instrument onboard EO-1 tests hyperspectral imaging techniques that can split the signal returned from the surface into hundreds of separate wavelength bands, an order of magnitude improvement in resolution over Landsat. EO-1 is flying in formation with Landsat and Terra so that their observations can easily be compared, making them a physical emblem of the best in remote sensing satellites of today, tomorrow, and decades to come. Another NMP mission is planned for 2005; Earth Observing-3 (EO-3) will carry the Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) developed at NASA Langley Research Center. GIFTS will allow tracking of the movement of water vapor through



The above image of South Africa's Kruger National Park was obtained by the Advanced Land Imager (ALI) on board the EO-1 spacecraft. ALI produces images comparable to Landsat at a fraction of the cost and size and continues the long-standing Landsat data record.

the atmosphere in all three spatial dimensions. GIFTS will give scientists the ability to observe the space and time distribution of temperature, water vapor, and wind, which will improve weather forecasting.

ESE Data and Information System Services
Terabytes of data come back from orbiting NASA satellites every day, providing society a greater capacity to assess the health of the Earth than ever before. This necessitates an efficient set of services to receive, process, and distribute the data.

The Earth Observing System Data and Information System (EOSDIS) has been handling existing data sets since 1994. It began working with raw satellite data following the launch of the Tropical Rainfall Monitoring Mission (TRMM) in November 1997. The system also manages data from other satellites such as Landsat 7 and Terra and provides command and control functions for Terra. EOSDIS works in tandem with NASA's primary satellite network, the Tracking and Data Relay Satellite System (TDRSS), and eight major remote sites called Distributed Active Archive Centers (DAAC's), each of which specializes in serving a particular scientific discipline. Scientific products for Terra are being generated in partnership with the mission's principal investigators and their home institutions. This trend will grow with future EOS missions and competitive selections of creative data processing proposals from universities and commercial providers. EOSDIS is accessible to scientists as well as the general public. It is based on an "open architecture" that can be updated as computer technology improves and research questions evolve over the coming decades.

The Federation of Earth Science Information Partners (ESIPs) was created in 1998 as an experiment in developing a federated system for data management. The notion was that this should be a decentralized, heterogeneous, and distributed data and information system taking EOSDIS data to the next step by generating products tailored by and for specific uses in society. The ESIPs combine their collective resources (data, technology, knowledge, and education) to increase the quality and widen the usage of Earth science data and create new interoperability tools for Earth data resources. They work to make it increasingly practical for end-users of Earth Science data to access information without having to navigate through a maze of data and cataloging issues.

NASA hopes to incorporate many of the "lessons learned" and technologies developed through the Federation of ESIPs as it plans for the evolution of Earth Science Data and Information System and Services. The Strategic Evolution of ESE Data Systems (SEEDS) plans to capitalize on the assets developed by EOSDIS and the ESIP Federation, as well as emerging information technology, so that the ESE can evolve its data and information system and services both to handle data from future missions and to involve and serve a broader range of information suppliers and users.

ESE Advanced Technology Program
In 1998, ESE established an Advanced Technology Program to meet the needs of its Research Strategy for new and lower cost instruments, computing, communications, and related technologies. A dedicated technology program allows technology development to take place offline from mission project development; systematic missions employ the best available technology, while exploratory missions are proposed only after needed technologies reach a sufficient level of maturity. The Earth Science Technology Office

ESE is engaged in teacher training and development of curriculum and support materials to expose students of all ages to the Earth Sciences. The GRACE Master Teachers Program is one example. The Texas Space Grant Consortium, funded by NASA, has worked closely with the GRACE mission team to develop interdisciplinary materials appropriate for teaching students from grades K-12 about the GRACE mission and related science.

(ESTO) located at Goddard Space Flight Center sponsors technology efforts that span the Technology Readiness Index from basic principles to spaceflight demonstration, primarily through open, competitive solicitations to draw the best ideas from academia, industry, and government laboratories.

ESE Partnerships

ESE accomplishes its mission and goals through an extensive network of academic, commercial, interagency, and international partnerships. ESE is the largest contributor to the interagency U.S. Global Change Research Program (USGCRP). Agreements with National Oceanic and Atmospheric Administration (NOAA), Department of Transportation (DoT), United States Department of Agriculture (USDA), Federal Emergency Management Agency (FEMA), United States Geological Survey (USGS), National Imagery and Mapping Agency (NIMA), and other federal, state, local and tribal agencies assure that ESE's research is broadly used in society. In the past three years over 60 international agreements have been concluded, and more than 40 more are pending. In some capacity, Earth science programs involve international partners from over 35 nations. NASA is an active participant in the World Meteorological Organization's World Climate Research Program and the United Nations Environment Program's International Geosphere-Biosphere Programme. Several boards and committees of the National Research Council are engaged in review of ESE programs. For each of the 12 NAI applications, NASA has formed partnerships with organizations with the appropriate information infrastructure to apply NASA results from Earth science to the application in question. The partners represent a wide range of federal, state, and local agencies including most of the ones listed above.

ESE Education Programs

Training the next generation of scientists and engineers and increasing the scientific literacy of all Americans is a high priority at NASA. ESE has established programs that span the formal education process, and a variety that support informal education through science museums and other means.
In formal education, ESE is engaged in teacher training (sponsoring nearly 500 workshops in fiscal year 2001) and development of curriculum support materials that are reviewed by educators to assure their utility in helping them meet national education standards. The Earth System Science Education project designs curricula at the college and university level, and helps those institutions design new undergraduate majors in this interdisciplinary field.

NASA also has a vested interest in training the next generation of scientists. The Graduate Student Fellowship Program sponsors 50 new graduate students each year to conduct new research. The New Investigator Program does the same for those who recently received their doctoral degrees. ESE is working on professional education projects to help meet the growing demand in the work force for people capable of using remote sensing data and geographic information systems.