NASA Facts

National Aeronautics and
Space Administration

Goddard Space Flight Center
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NASA'S EARTH SCIENCE ENTERPRISE and THE GODDARD SPACE FLIGHT CENTER

Beginning in the 1960s, NASA pioneered the study of the Earth from the unique perspective of space. These early efforts have matured to the point where it is now possible to study the Earth as a global system. *Earth System Science* is the integration of many scientific disciplines such as meteorology, oceanography, biology and atmospheric science. The research seeks the understanding of the entire planet, its integral parts and how their interactions function. Through this research, scientists are beginning to better understand short-term weather phenomena that are connective in nature. Long-term weather forecasting is a challenge that needs more data collection, trend analysis, and a clearer understanding of the interactions between the Earth's physical and biological systems.

Earth's climate has evolved in the past and continues to evolve today. These changes span a wide spectrum of space and time. More immediate effects of our changing climate can be seen in altered weather patterns - such as the *effects* of El Niño. Though now we are just recently beginning to understand El Niño, our current lack of understanding of these changes diminishes our ability to respond - both before and after the event.

The Earth Science Enterprise

In 1991, NASA began a global-scale examination of the Earth to study the interaction of all the environmental factors - air, water, land, and plant and animal life - that make up the Earth system. The goal of this program, called *the Earth Science Enterprise* (formerly known as Mission to Planet Earth), is to improve our understanding of the Earth and develop accurate predictive computer models that can help inform decision makers about global environmental trends, allowing us to protect the planet's and humanity's future.

The Earth Science Enterprise has three main components: a series of Earth-observing satellites, an advanced data system and teams of scientists who will study the data. Key areas of study include clouds; water and energy cycles; oceans; chemistry of the atmosphere; land surface; water and ecosystem processes; glaciers and polar ice sheets; and the solid Earth.

Phase I of the Earth Science Enterprise has been comprised of focused, free-flying satellites, Space Shuttle missions, and various airborne and ground-based studies. Phase II begins with the launch of the Earth Observing

System (EOS) AM-1 spacecraft. EOS will feature a series of polar-orbiting and low inclination satellites for global observations. EOS will help us to understand how the complex coupled Earth system of air, land, water and life is linked.

EOS is the centerpiece of this enterprise and is managed by NASA's Goddard Space Flight Center, Greenbelt, Md. In addition, many of the enterprise science priorities are accomplished by NASA's Jet Propulsion Laboratory, Pasadena, Calif., Langley Research Center, Hampton, Va., Marshall Space Flight Center, Huntsville, Ala., and Stennis Space Center, Bay St. Louis, Miss.

From the very beginnings of the program, NASA has worked closely with university, government and industry scientists, to identify five specific areas of scientific research that will have significant benefit to all humankind. They include:

• *Land Cover Change and Land Use Change*: The program will observe how land and coastal regions are changing over time due to both natural and human activities.

• *Seasonal-to-Interannual Climate Variability and Prediction*: Understanding how to accurately forecast precipitation and other variables, one season or even one year in advance could have an enormous impact on agricultural planning.

• *Natural Hazards Research and Applications*: Much of the previously mentioned capabilities can be used to project the probabilities of floods and droughts in key regions of the nation and the world.

• *Long-Term Climate Variability*: Constructing computer models of climate change that extend annual prediction capabilities to decades or centuries will help ascertain the difference between natural and human-induced drivers of climate change.

• *Atmospheric Ozone*: This research will increase our knowledge of ozone depletion in the upper atmosphere and help to identify substitutes for harmful chemicals. In addition, it will begin a monitoring effort of the lower atmosphere ozone which is toxic to most life.

Just as the first weather and communications satellites fundamentally changed our way of weather forecasting and communicating, so the elements of the Earth Science Enterprise will expand our perspective of the global environment and climate.

National and International Cooperation

The Earth Science Enterprise is NASA's contribution to the U.S. Global Change Research Program, a multi-agency effort to understand how our Earth changes over time. The U.S. program complements a larger international effort to study the environment, including the International Biosphere Geosphere Program and the World Climate Change Research Program. International cooperation on NASA missions includes the flight of other nations' instruments aboard NASA satellites and provision of NASA experiments onforeign spacecraft.

Goddard - Yesterday and Today

NASA's Goddard Space Flight Center, named for Dr. Robert H. Goddard, a pioneer in rocket research, was established in 1959. Since that time, Goddard has played a major role in Earth science research.

The Goddard team is made up of some of the world's premier scientists and engineers devoted to research in Earth science. Goddard's fundamental mission is to expand knowledge of the Earth and its environment, the solar system and the universe through observations from space. To ensure the nation maintains leadership in this endeavor, the Center is committed to excellence in scientific research and investigation, in the development of space systems and in the advancement of essential technologies.

NASA and their scientists from Goddard are focusing research on this new "Earth System Science," the atmosphere, oceans, land, ice and snow, and their influence on climate and weather.

The Science

Ozone

Since the launch of the first Total Ozone Mapping Spectrometer (TOMS) aboard the Nimbus-7 polar-orbiting satellite in 1978, NASA has provided scientists with reliable, high-resolution daily maps of global ozone levels. Managed by Goddard, TOMS is a primary source of data on global ozone day-to-day variability and long-term trends. TOMS/Nimbus-7, the first TOMS instrument, provided reliable, high-resolution maps of global ozone amounts on a daily basis from October 1978 to May 1993. Ozone-depletion data from TOMS underpins several international agreements to phase out the use of chlorofluorocarbons or "CFCs" and other ozone-depleting chemicals.

During its lifetime on Nimbus-7, TOMS helped make "ozone" a household word through false-color images of the Antarctic ozone hole. Even after 14 years of operations, TOMS was testing new concepts such as "now-casting" of winds at flight altitudes and volcanic ash clouds. Now-casting is real-time ozone mapping that occurs when satellite data is processed and displayed on a computer screen simultaneously as the satellite passes overhead. In April 1993, during an early morning pass of NASA's Nimbus-7, scientists were able to take real-time ozone readings from TOMS.

Analyses of TOMS data have traced in detail the annual development of the Antarctic "ozone hole," a large area of intense ozone depletion that occurs between late August and early October. The ozone hole was discovered through British ground-based observations in the mid-1980s, but analysis of TOMS data indicates it has existed since at least 1979.

TOMS data also have shown a long-term depletion of ozone in the Northern Hemisphere's mid-latitudes, reaching record lows in late 1992 and early 1993. The possibility that increased ultraviolet radiation could reach the Earth's surface during the beginning of the growing season raises questions of significant economic, environmental and health effects.

The Meteor-3/TOMS, the first significant U.S. science instrument to fly on a Russian spacecraft, was one of the main sources of ozone data until the launch of TOMS/Earth Probe. Meteor-3/TOMS, provided by NASA, was launched in Aug. 15, 1991 from Plesetsk in what was then the Soviet Union and ensured continuity of data when Nimbus-7/TOMS ceased operating in May 1993. A third TOMS, onboard an Earth Probe satellite, was launched in 1996, and the Japanese Advanced Earth Observations

TOMS Total Ozone Image-March 1997

Satellite (ADEOS) carried a fourth TOMS in late 1996. A fifth TOMS is scheduled for launch in 2000 aboard a Russian Meteor-3M satellite.

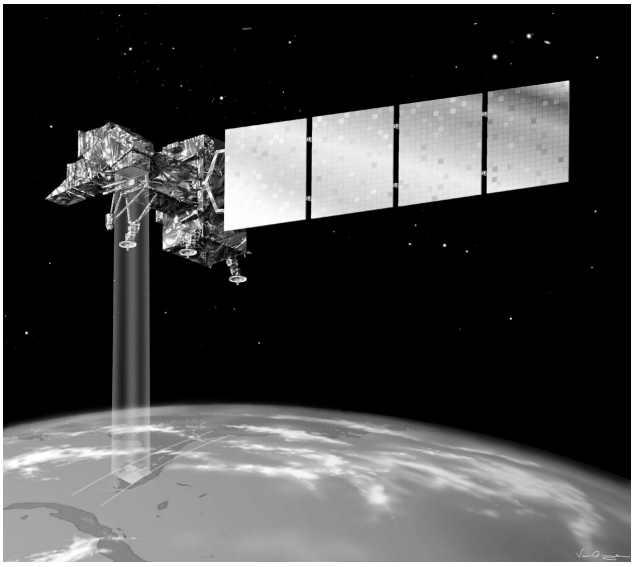
A long-term, consistent record of ozone levels is essential to understanding and predicting ozone depletion. To ensure that ozone data will be available throughout the next decade, NASA has been continuing the TOMS program using U.S. and international launches.

Land

The Earth's surface is changing consistently. From volcanic eruptions to hurricanes, nature changes the surface of the Earth. Meanwhile, human activity is a powerful force in its

own right. Currently, nearly one-half of all people live in urban areas. By the year 2025, 60 percent will live in urban areas. Satellites are helping urban planners guide development in ways to minimize the impact on our planet. This is just one example of how a NASA developed satellite, called "Landsat," is helping to understand the changing Earth.

Landsat satellites produced the first composite multi-spectral mosaic of the 48 contiguous United States. They have been used to monitor timber loses in the U.S. Pacific Northwest, to estimate soil moisture and snow water equivalence and to measure forest cover at the state level. In addition, Landsats have been used to monitor strip mining reclamation, population changes in and around metropolitan areas and to measure water quality in lakes. Landsat images have even been used by law firms to gather legal evidence and by the fast food restaurants to estimate community growth sufficient to warrant a franchise.



Orbiting Landsat-7 Spacecraft

The latest mission in the Landsat series, Landsat-7, is being built to continue the flow of global change information to users worldwide.

Scientists use Landsat satellites to gather remotely sensed images of the land surface and surrounding coastal regions for global change research, regional environmental change studies, national security uses and other civil and commercial purposes. Landsat-7 is a joint program with NASA, the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey sharing responsibilities for the Landsat-7 program.

The first Landsats, originally called ERTS for Earth Resources Technology Satellite, were developed and launched by NASA between July 1972 and March 1978. During that time, a second generation of Landsat satellites was developed. Landsat-4 was launched in July, 1982 and Landsat-5 in March 1984. Landsat-5 still is receiving images.

The scientific mission of Landsat-7 is to extend and improve upon the more than 25-year record of images of the Earth's continental surfaces provided by the earlier Landsat satellites. The continuation of this work is an integral component of the U.S. Global Change Research Program. Landsat-7 also will continue providing essential land surface data to a broad, diverse community of national security, civil and commercial users.

No other current or planned remote sensing system, public or private, fills the role of Landsat in global change research or in national security, civil and commercial applications.

Weather

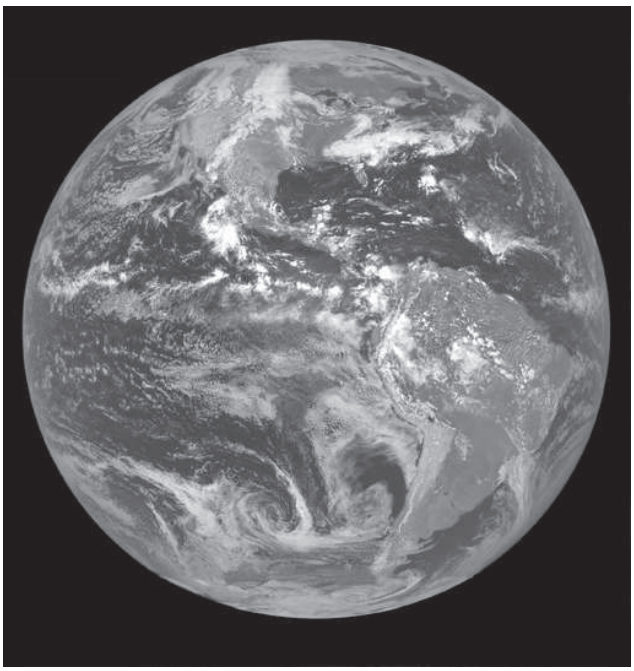
Goddard also is responsible for the procurement, development and verification testing of the Geostationary Operational Environmental Satellite (GOES) system. The GOES system consists of a series of geostationary weather satellites developed and launched by NASA for NOAA as part of the U.S. Weather Services modernization program. The GOES satellites provide the pictures for television news weather reports.

The latest GOES satellite, GOES-10, was launched on April 24, 1997, where it joined its predecessors GOES-8, launched in April 1994, and GOES-9, launched in May 1995. The GOES-10 satellite, was being stored "on-orbit"

until the aging GOES- 9 spacecraft was deactivated.

Currently, the GOES-10 spacecraft is positioned to view the western U.S., West Coast, Hawaii, Alaska, and the Pacific. It provides atmospheric images, temperature and humidity profiles, wind velocity data, and severe storm coverage of the Earth's western hemisphere. GOES-10 was activated on July 9, 1998 by the NOAA to replace GOES-9. Immediate activation of the satellite that was stored in orbit was possible due, in large part, to innovative measures by NASA Goddard engineers. The Goddard team was able to correct a potentially fatal problem with the GOES-10 solar array which occurred shortly following the launch in 1997. GOES-8 overlooks the East coast of North adn South America adn the Atlantic Ocean.

The new series of GOES satellites have improved greatly weather forecasting by providing state-of-the-art weather images and atmospheric sounding information.



Earth-view from GOES Spacecraft

Goddard also is responsible for the construction, integration, launch and verification testing of the spacecraft, instruments and unique ground equipment of NOAA's Polar-Orbiting Operational Environmental Satellites (POES), which observe our Earth and provide

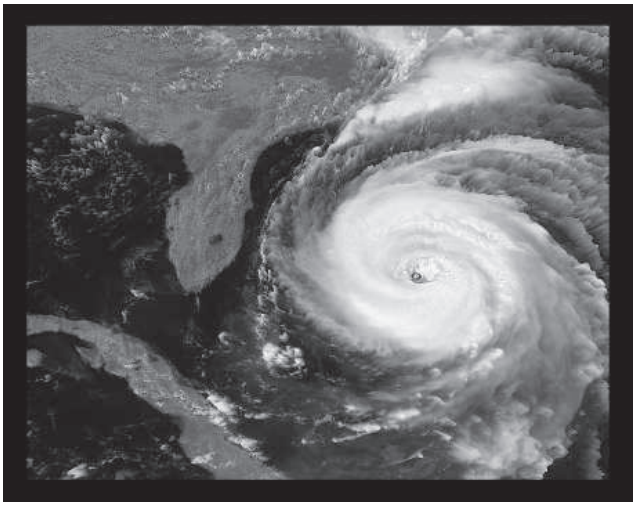


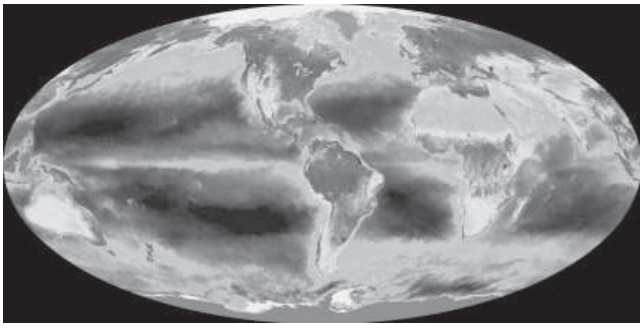
Image of Hurricane Fran - data from GOES. Enhanced and rendered by Goddard

global data for NOAA's operational user requirements including short and long-range weather forecasts. Data from the GOES and POES spacecraft are used by Goddard scientists for weather and climate research and helps NASA scientists design instruments for future missions.

Oceans

The color of most of the world's oceans varies with the concentration of microscopic marine plants, called "phytoplankton," which contain chlorophyll, a green pigment. Near coastlines, the color of the ocean is affected by chlorophyll, disolved organic material and suspended sediments from rivers and lagoons. By observing the color of different parts of the oceans, scientists can measure the amount of these materials in the water. Phytoplankton concentrations in the ocean is essential in understanding the role of the oceans in the global carbon cycle—the process by which carbon travels through the Earth's atmosphere, oceans, land, and living organisms. Phytoplankton removes carbon from the atmosphere for internal use. Scientists want to understand this exchange of carbon and the role it plays in the global climate.

NASA scientists are using a new satellite to measure phytoplankton. The Sea-viewing Wide Field-of-view Sensor (SeaWiFS) sensor is observing the world's oceans from space to measure "ocean color." SeaWiFS represents a new way of doing business for NASA. Rather than building, launching and controlling a satellite, NASA is purchasing commercially available data from a privately built satellite and uses the data for environmental research.



SeaWiFS Image of Global Biopshere

The first readily available ocean-color data in more than ten years, SeaWiFS is playing a major role in studying El Niño and in other global warming research. The data also are giving scientists their first continuous look at the global biosphere — the combination of living organisms and their environment. Ocean color is largely determined by the concentration of the microscopic marine plants. Accurately measuring phytoplankton concentration is important to climate change research and to local economic concerns such as commercial fishing.

For example, the increased carbon dioxide in the Earth's atmosphere since the Industrial Revolution had led some scientists to conclude the Earth's temperature was rising. However, the exact "map" of the global carbon cycle is poorly understood, making it difficult to accurately predict the response of global climate to changes such as increases in carbon dioxide. SeaWiFS data will help scientists understand one important portion of the carbon cycle.

Similarly, a NASA spacecraft scheduled to launch in the fall of 1998 will study ocean winds. The SeaWinds instrument on the Quik Scatterometer (QuikSCAT) satellite is a specialized microwave radar that measures near-surface wind speed and direction under all weather and cloud conditions over Earth's oceans.

QuikSCAT was initiated to help reduce the ocean-wind vector data gap created by the loss of the NASA Scatterometer (NSCAT) on the Japanese ADEOS spacecraft, which ceased functioning when ADEOS failed on June 30, 1997. QuikSCAT is planned for launch from Vandenberg Air Force Base, Calif., aboard a Titan II vehicle, reducing the data gap by about one-half.

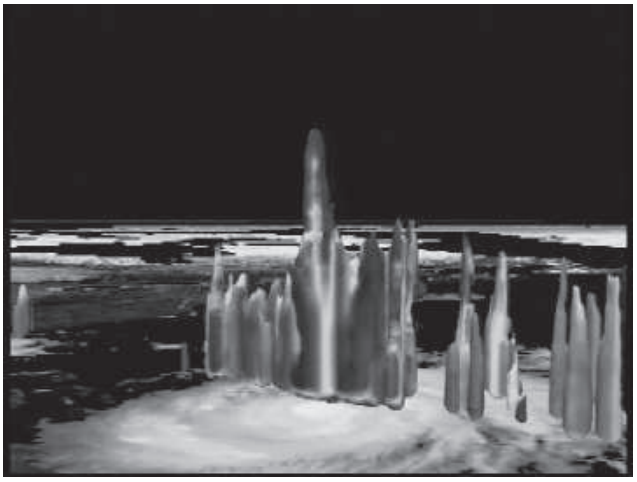
QuikSCAT represents a unique collaboration between NASA's Jet Propulsion Laboratory (JPL) and Goddard. JPL's NSCAT/SeaWinds program office has been assigned the QuikSCAT management responsibility and will provide management, ground systems and a SeaWinds-type scatterometer instrument. Goddard has procured the satellite under the newly instituted Indefinite Delivery/Indefinite Quantity (ID/IQ) contract system for rapid delivery of satellite core-systems. ID/IQ enables a quick acquisition of a science bus to support NASA's space science, Earth science and technology needs.

QuikSCAT is the first delivery order issued under the ID/IQ procurement method and provides NASA a faster, better, cheaper method for the purchase of satellite systems through a "catalog," allowing for shorter turnaround time from mission conception to launch.

Rainfall

Another part of NASA's Earth Science enterprise is the Tropical Rainfall Measuring Mission (TRMM) which launched on Nov. 27, 1997. TRMM, a joint project between NASA and the National Space Development Agency of Japan (NASDA), is the first satellite designated

to observe tropical rainfall. Goddard was responsible for providing the observatory, two of its five instruments, integration and test of the observatory and the science data processing system. Goddard operates TRMM via the Tracking and Data Relay Satellite System.



TRMM Observation of Hurricane Bonnie "Tall Chimney Clouds," towering 59,00 feet

Data has shown that TRMM is exceeding expectations for accuracy and resolution and the spacecraft is providing scientists with their first-ever measurements of rainfall over the planet's oceans. TRMM has the ability to peer into the inner structure of storms and its ability to more precisely measure how much precipitation results from both heavy thunderstorms and light rain showers.

The TRMM spacecraft fills an enormous void in the ability to calculate world-wide precipitation because so little of the planet is covered by ground-based radars. Presently, only three percent of all of the Earth's land is covered by ground-based radars, and there are no "ocean-based" radars over the oceans. Global rainfall is the primary distributor of heat through the circulation of the atmosphere, thus more precise information about this rainfall and its variability is crucial to understanding and predicting global climate change.

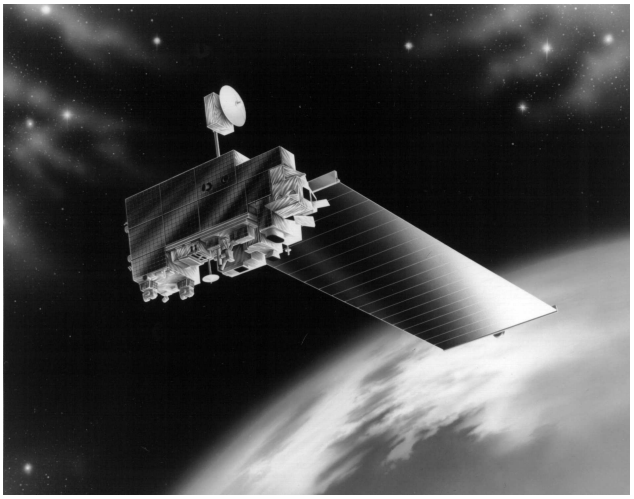
One of TRMM's instruments, the Precipitation Radar, is the first spaceborne rain radar ever launched into space. It measures precipitation distribution over both land and ocean.

Upcoming Missions

EOS AM-1

NASA's commitment to studying the Earth as a global system continues with the Earth Observing Spacecraft AM-1 and represents a key contribution by NASA to the U.S. Global Change Research Program. EOS AM-1 is the first of several EOS spacecraft. AM-1 will observe the Earth's continents, oceans and atmosphere with five state-of-the-art instruments achieving measurement capability and accuracy never flown before. This comprehensive approach enables scientists to study the interactions among these three components of the Earth system, which determine the cycling of water and nutrients on Earth.

EOS AM-1 simultaneously will study clouds, water vapor, small particles in the atmosphere called "aerosol" particles, trace



Orbiting EOS AM-1 Spacecraft

gases, land surface and oceanic properties, as well as the interaction between them and their effect on the Earth's energy budget and climate.

Moreover, EOS AM-1 also will observe changes in the Earth's radiation energy budget,

together with measurements of changes in land/ocean surface and interactions with the atmosphere through exchanges of energy, carbon and water. Clearly comprehending these interactive processes is essential to understanding global climate change.

A polar-orbiting spacecraft, EOS AM-1 is scheduled for launch aboard an Atlas IIAS launch vehicle from Vandenberg Air force Base. NASA's Kennedy Space Center, Fla., is responsible for launch operations and NASA's Lewis Research Center, Cleveland, is responsible for the Atlas launch vehicle under a contract with Lockheed Martin Astronautics, Denver.

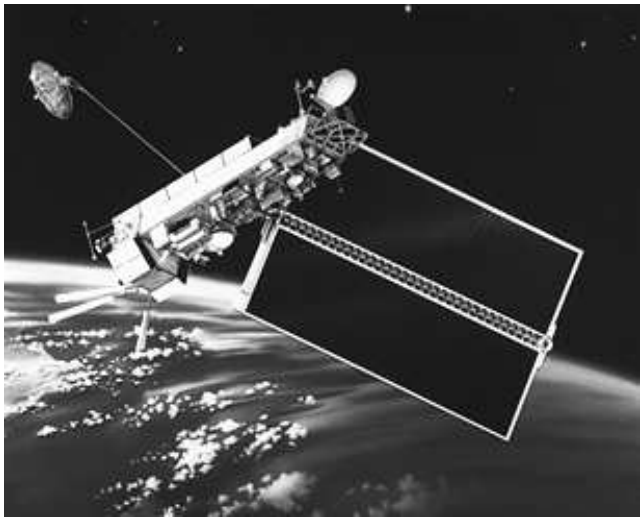
EOS AM-1 will orbit the Earth in synch with the Sun, with its path over the ground descending across the equator at the same local time every day - approximately 10:30 a.m. - hence the term "**AM**." A morning observation minimizes the time in which clouds obscure the land surface - optimizing observing time. Mornings over land typically have clear skies whereas the mornings over the oceans are more often cloudy. EOS AM-1 will orbit at an inclination of 98 degrees to the equator and at a mean altitude of 380 nautical miles (705 kilometers). AM will be followed by its "PM" spacecraft counterpart in the year 2000.

EOS AM-1 is a joint project between the United States, Japan and Canada. The U.S. provided the spacecraft and three instruments - the Clouds and the Earth's Radiant Energy System (CERES), the Multi-Angle Imaging Spectroradiometer (MISR) and the Moderate-Resolution Imaging Spectroradiometer (MODIS). The Japanese Ministry of International Trade and Industry provided the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). The Canadian Space Agency/University of Toronto provided an instrument called the Measurements of Pollution In The Troposphere (MOPITT) instrument.

Goddard provided the spacecraft data interface system or "bus" and the MODIS instrument. In addition, Goddard managed the integration and testing of the spacecraft and will operate EOS AM-1 via the Tracking and Data Relay Satellite System. Goddard will receive, process, and disseminate science data through the Earth Observing System Data and Information System (EOSDIS). EOS AM-1 is managed by Goddard for the Earth Science strategic enterprise. MISR was provided by JPL and the two CERES instruments were provided by NASA's Langley Research Center, Hampton, Va. Integration and test of the spacecraft is being performed by Lockheed Martin under Goddard management. The EOS AM-1 spacecraft was assembled and tested by Lockheed Martin at its Valley Forge, Pa., production facility.

EOS PM-1

Global change is inevitable and has been ongoing for hundreds of millions of years. The Sahara Desert was once lush and fertile, North America a bleak glacial landscape and the Great American Desert a seabed.



Orbiting EOS PM-1 Spacecraft

While it is easy to view environmental change from the distance afforded by thousands of years, our understanding of the causes and effects of ongoing change is still incomplete.

What causes the slight, subtle changes that influence our environment? Research has gleaned some answers to these complex questions, but scientists need a learn more about our

changing planet.

The EOS PM-1 mission, the second EOS spacecraft, is scheduled to launch in December 2000 aboard a Delta II rocket from Vandenberg Air Force Base. Like its sister AM-1, PM-1 is a polar-orbiting sun-synchronous spacecraft and will study clouds, precipitation and radiative balance. EOS PM-1, however, will fly in an *ascending* orbit with a 1:30 p.m. equatorial crossing time. PM-1 is a cooperative effort between NASA and the collaboration of scientific and industry organizations in Japan and Brazil.

NASDA of Japan will provide the Advanced Microwave Scanning Radiometer-EOS (AMSR-E) to fly on the PM-1 satellite. PM-1 AMSR-E is being modified from the AMSR design and built by Mitsubishi Electronics Corporation for deployment on the Japanese ADEOS-II scheduled for launch in 1999. It will observe atmospheric, land, oceanic, and cryospheric parameters, including precipitation, sea surface temperatures, ice concentrations, snow depth and water content, surface wetness, wind speed, atmospheric cloud water, and water vapor.

The AMSR-E is a passive forward-looking scanning microwave radiometer. The AMSR data will be used to provide precipitation rate water vapor content and surface moisture content.

EOS PM-1 will fly in a orbit that covers the globe every 16 days, compiling a six year chronology of the planet and it's processes. Comprehensive measurements taken by it's onboard instruments will allow scientists to assess long-term change, identify its human and natural causes and advance the development of models for long-term forecasting.

ICESAT-1

ICESAT-1, for Ice, Cloud and land Elevation Satellite, formerly known as the Laser Altimetry Mission, will measure accurately the elevations of the Earth's ice sheets, clouds, and land and answer fundamental questions about the growth or shrinkage of the Earth's polar ice sheets and future global sea level rise or fall. ICESAT also will measure the heights of clouds for studies of Earth's temperature balance and will measure land topography for a variety of scientific and potential commercial applications.

Ball Aerospace, Boulder, Colo., will provide the spacecraft and will integrate and test the primary instrument on the ICESAT satellite, the Geoscience Laser Altimeter System. The laser altimeter is being developed at Goddard and will provide precise elevation of the land, ice and clouds.

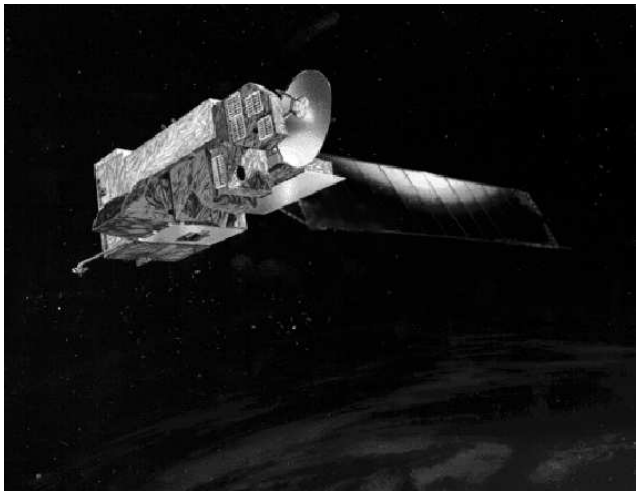
The laser is completely eye-safe to individuals on the ground and works by transmitting short pulses of infrared light and visible-green light to measure ice sheet elevation and land topography (infrared light) and measurements of clouds and aerosols (green light). The distance from the spacecraft to clouds and to Earth's surface will be determined from measurements of the time taken for the laser pulses to travel to these targets and return. Similar instrumentation has been flown on aircraft over the Greenland ice sheet for proof-of-concept experiments.

The Greenland and Antarctic ice sheets cover 10 percent of the Earth's land area, contain 77 percent of the Earth's fresh water and 99 percent of its glacier ice. Measurements of the ice sheets are essential for assessing whether future changes in ice volume will add to the sea level rise, which is already occurring, or whether the ice sheets might grow and absorb a significant part of the predicted sea level rise.

ICESAT is being developed by a partnership of NASA, industry and university teams. ICESAT will be placed into an orbit 379 miles above the Earth with an inclination of 94 degrees to the equator. A launch vehicle for the ICESAT mission will be selected from the stable of medium-light expendable launch vehicles. ICESAT's designed lifetime is for three years of operation with a five-year goal.

EOS CHEM-1

The Earth's climate is regulated in part by chemicals and particles in the atmosphere. The complex interactions of these constituents from both natural sources, such as biological activity and volcanoes, and man-made sources, such as biomass burning, are contributing to global change and effect the creation and depletion of ozone.



Orbiting EOS CHEM-1 Spacecraft

EOS CHEM-1 mission is to study the chemistry and dynamics of the Earth's atmosphere from the ground through the mesosphere. This mission will provide the first global measurements of several important tropospheric chemicals.

The Chemistry Mission was established in December 1991 and is scheduled to be launched in December 2002 on a medium expendable launch vehicle from Vandenberg Air Force Base. The Chemistry Mission is composed of four complementary instruments placed on the EOS Common Spacecraft which is being built by TRW (Space and Electronics Group). The observatory will be launched into a 440 miles (705 kilometer), 98.2 degree inclination, polar sun synchronous orbit. It will have an ascending node equatorial crossing time of 1:45 p.m.

The instruments will employ advanced technologies to measure highly reactive gasses that only appear in extremely low concentrations. The instruments will scan the atmosphere in the ultraviolet, visible, infrared and microwave regions of the Earth's outward radiating spectrum. The measurements will cover the entire globe, which will enable tracking on regional and continental scales, and begin the investigation of the subtle interactions between the lower and upper atmosphere.

The High Resolution Dynamic Limb Sounder (HIRDLS) is an infrared limb scanning radiometer designed to sound the upper troposphere, stratosphere and mesosphere; it is a collaboration between the University of Colorado and Oxford University in the United Kingdom. The Microwave Limb Sounder (MLS) is designed to measure numerous chemical species, such as hydroxyl radical. The Tropospheric Emission Spectrometer (TES) is a high-resolution infrared imaging Fourier transform spectrometer which is an ozone monitoring-type instrument and will focus on global mapping of ozone. Both MLS and TES are being provided by JPL.

The Data System

The end product of the Earth Science Enterprise will be the ability to develop and implement strategies that will improve human interaction with the Earth's environment based on a better understanding of how our environment works. To develop that understanding, the Earth Science Enterprise will rely on the EOS Data and Information System (EOSDIS). The EOSDIS has been designed to archive, manage and distribute Earth Science data worldwide. EOSDIS will relay large amount of information to scientists, educators, governments, businesses, and the general public. Through EOSDIS, any data set may be accessed via the Internet, and other means, by thousands of users, simultaneously, throughout the world.

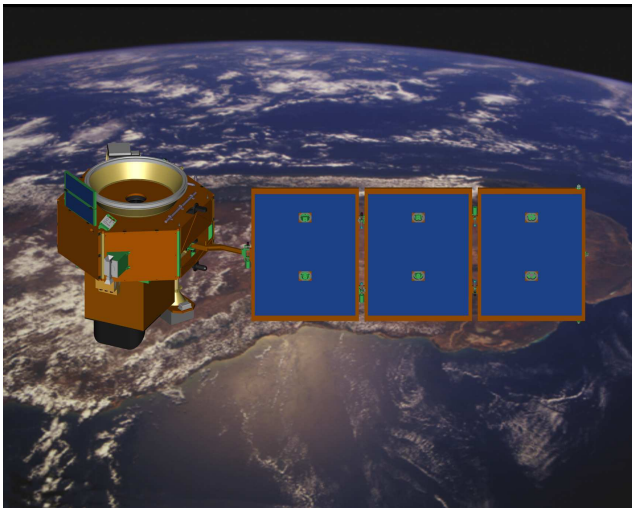
The Technologies of Tomorrow

New Millennium Program

The New Millennium Program, started in 1996, is designed to identify, develop, and flight-

validate key instrument and spacecraft technologies that can enable new or more cost-effective approaches to conducting science missions in the 21st century.

The first mission, Earth Orbiter (EO)-1, is designed to demonstrate detector technology that will be used to provide advanced Landsat imagery (post Landsat-7) and will feature an Advanced Land Imager (ALI) instrument. The new instrument will demonstrate remote-sensing measurements of the Earth consistent with data collected since 1972 through the Landsat series of satellites, which is used by farmers, foresters, geologists, economists, city planners and others for resource monitoring and assessment. In



Orbiting EO-1 Spacecraft

addition, it will acquire data with finer spectral resolution, a capability long sought by many elements of the Earth observation data user community, and it will lay the technological groundwork for future land imaging instruments to be more compact and less costly. Evolutionary versions of ALI would be candidates for flight on future generations of NASA EOS missions, beginning with the AM-2 spacecraft.

Additional instruments include: *the Atmospheric Corrector* (AC) instrument and the *Hyperion* instrument. The AC will provide the first space-based test of an atmospheric corrector for increasing the accuracy of surface reflectance estimates. The AC is applicable to any scientific or commercial Earth remote sensing mission where atmospheric absorption due to water vapor or aerosols degrades surface reflectance measurements. Using the AC, instrument measurements of actual rather than modeled absorption values, enables more precise predictive models to be constructed for remote sensing applications.

The Hyperion (Hyperspectral) instrument provides a new class of Earth observation data for improved Earth surface characterization. The Hyperion capabilities provide resolution of surface properties into hundreds of spectral bands versus the ten multispectral bands flown on traditional Landsat imaging missions. Through this large number of spectral bands, complex land eco-systems will be imaged and accurately classified. The instrument, originally conceived as a drop-in to the ALI instrument, is now baselined to be a standalone instrument on EO-1.

Goddard Space Flight Center has project management and implementation responsibility for technology validation of EO-1 and EO-2.

Under project management by Goddard, the ALI will be developed from instrument technologies proposed by members of the existing New Millennium Integrated Product Development Teams. For this mission, the team of industry partners will be led by the Massachusetts Institute of Technology's Lincoln Laboratory, Lexington, Mass., a federally funded research and development center. Lincoln Lab and its partners will provide open access to U. S. industry regarding the design and performance of the Advanced Land Imager, with the explicit purpose of expediting the transfer of this technology into the commercial sector.

The second New Millennium program mission, Earth Orbiter (EO)-2, is designed to measure the winds in clear air. NASA's Marshall and the Global Hydrology and Climate Center have been selected to develop the Space Readiness Coherent Lidar Experiment (SPARCLE), a test model of a large-scale laser that could measure winds across the planet where there are no instruments. NASA/Marshall is the lead center and will work closely with

Langley Research Center and the Jet Propulsion Laboratory in developing SPARCLE.

SPARCLE will start with a modest size; two Getaway Specials (GAS) canisters flown onboard the Space Shuttle in the cargo bay. These GAS cans are the size of a large wastepaper basket. Using a "GAS can" will allow scientists to put their optical and electronic systems in a pressurized environment and not have to ruggedize them for direct exposure to space.

SPARCLE will aim pulses of eye-safe laser light into the atmosphere and measure the light which is reflected back to it by dust and aerosols in the atmosphere. The time between pulse and echo will (like radar) determine the distance to an object. The shift in the color of the light will tell how fast the particles are moving along the laser's line of sight. A transmitter laser will send a pulse of low-intensity infrared light through a telescope to the Earth below. A rotating glass wedge will allow some pointing control since the GAS cans are firmly bolted to the side of the Shuttle payload bay.

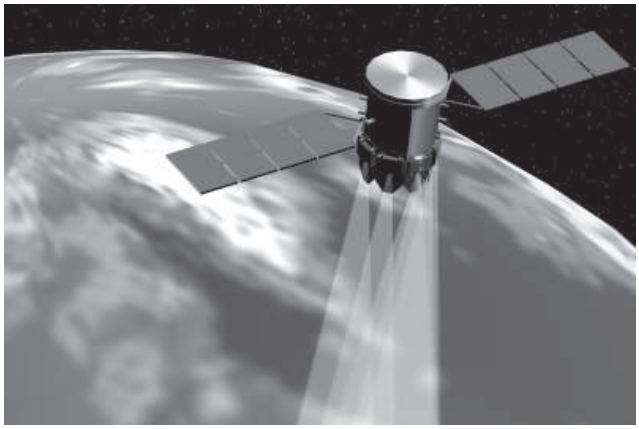
The return signal will be combined with another laser beam so the two interfere slightly to yield a more easily measured radio wave in place of the two light waves. The technique is called heterodyning. The frequency of the radio wave will match the difference between the outgoing and incoming signals (adjusted so the system is not acting as a speedometer for the Shuttle).

The overall New Millennium program is managed by JPL for NASA's Office of Space Science, Office of Space Access and Technology, and Office of Earth Science, Washington, D.C.

Earth System Science Pathfinder

The Earth System Science Pathfinder (ESSP) Program is designed to achieve maximum science value while complementing existing or planned flight missions. In the Principal Investigator (PI) mode for implementing ESSP, the single PI and team are ultimately responsible for developing the flight mission hardware from selection to a launch-ready condition in 36 months, with minimal direct NASA oversight. The PI and mission team are responsible for accomplishing the stated scientific objectives and delivering the proposed measurements to the broader Earth science community and general public as expediently as possible.

The first mission, the Vegetation Canopy Lidar (VCL) mission, led by Dr. Ralph Dubayah of the University of Maryland, College Park, seeks to provide the first global inventory of the vertical structure of forests across Earth using a multibeam laser-ranging device. VCL will enable direct measurement of tree heights, forest canopy structure, and derived parameters such as global biomass with at least ten times better accuracy than existing assessments. The laser mapping technique to be used by VCL, which was pioneered by NASA in aircraft experiments several years ago, should help resolve a major uncertainty in the scientific understanding



Orbiting VCL Spacecraft

of the global carbon cycle, particularly the role of terrestrial ecosystems in sequestering the atmospheric carbon dioxide produced by industrial activities and automobile exhausts.

VCL uses a pulsed laser radar (lidar) from a small single-instrument spacecraft in a 65 degree inclination, 250 mile (400 kilometer) altitude, circular Earth orbit. The lidar instrument, Multi-Bean Laser Altimeter is designed for continuous global remote sensing of tree canopy height, other surfaces in the canopy, and

ground topography. The instrument will generate a vast array of reference points for future surveys of land topography, including the planned NASA-Department of Defense Shuttle Radar Topography Mission in 1999-2000. VCL measurements also should have practical commercial applications in forestry management. VCL will be launched in spring 2000 on a Pegasus launch vehicle. Industrial partners in VCL include CTA Space Systems, McLean, Va.; Fibertek Inc., Herndon, Va.; and Omitron Inc., Greenbelt, Md., with participation by scientists at Goddard and several U.S. universities.

The second ESSP mission is the Gravity Recovery and Climate Experiment (GRACE), led by Dr. Byron Tapley of the University of Texas at Austin, GRACE employs a satellite-to-satellite microwave tracking system between two spacecraft to measure the Earth's gravity field and its time variability over five years. Such measurements are directly coupled to long-wavelength ocean circulation processes and to the transport of ocean heat to Earth's poles. GRACE includes major international cooperation through Dr. C. Reigber as Co-Principal Investigator fromGeoForschungs-Zentrum (GFZ) in Potsdam, Germany. GRACE will provide a framework for studying the gravitational signatures of gigantic continent-sized underground water reservoirs, or aquifers. It also will provide a never-before-available perspective on global ocean circulation and the time variability of Earth's overall external shape, or geoid. This fundamental dataset could enable great improvements in existing ocean radar altimetry data sets, and retrospective improvements of seasonal to interannual climate change estimates. Through an innovative teaming arrangement, GRACE's German partner GFZ will provide mission operations and a Russian booster for a spring 2001 launch, greatly reducing the direct total cost to NASA. Other partners include Loral Space Systems, Palo Alto, Calif.; the JPL and Dornier of Germany to build the spacecraft.

The Future

As we approach the 21st century, NASA Goddard, together with our partners around the world, are using satellite technology and global remote sensing to give Americans and people around the world a thorough understanding of the state of the planet and the intricate and interdependent systems which support life.

More information on the Earth Science Enterprise can be found on the internet at: http://www.hq.nasa.gov/office/ese/ or http://sdcd.gsfc.nasa.gov/ESD/.