S P E C I A L E D I T I O N

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Goddard Space Flight Center

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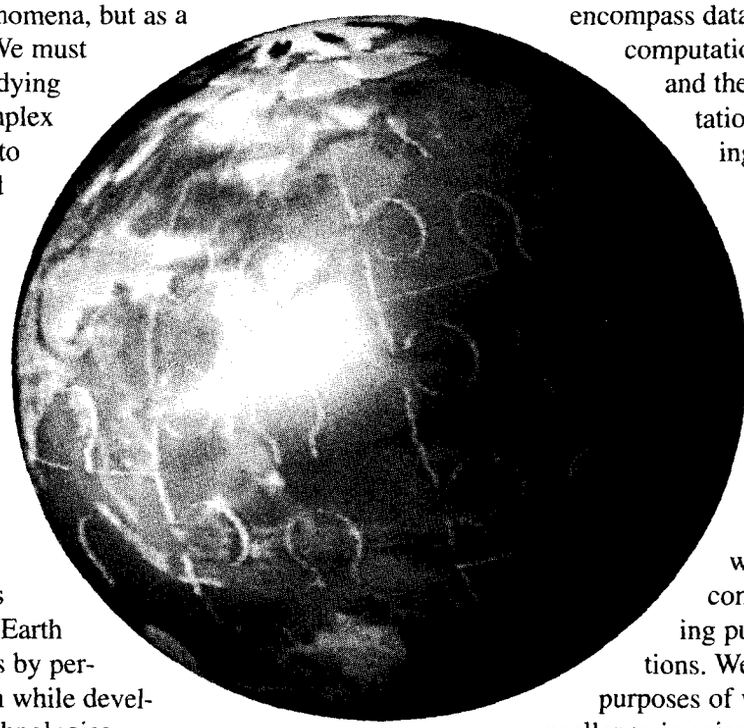
1970 • EARTH DAY • 1995

This special edition of the Goddard News is devoted to the research activities of the Earth Sciences Directorate which supports NASA's Mission to Planet Earth Program. This issue offers a few examples, illustrations, and explanations of the diverse and complex world of Goddard's Earth systems scientists.

Earth is not a jigsaw puzzle with separate domains of land, sea, and atmosphere. After centuries of study we have learned that Earth's components and processes do not function as separate phenomena, but as a set of interrelated systems. We must abandon old practices of studying discrete elements of our complex planet and apply our efforts to the evolving approach called Earth Systems Science. This approach recognizes that the so-called "discrete elements" of Earth's behavior are really interdependent phenomena whose interactions can best be understood from simultaneous, multi-disciplinary studies. This recognition drives our mission of providing leadership to improve observations and understanding of global Earth systems processes and trends by performing world class research while developing and utilizing space technologies.



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Concurrently, we will provide enabling functions in support of associated projects and programs of our Center, the agency, and the Earth Sciences community worldwide. Our mission and activities will make us a comprehensive national resource for studies of Earth from space. Our goal of achieving preeminence in Earth Sciences will encompass data analysis and modeling, computational support and data access, and the development and implementation of instrument and computing systems.

The celebration of Earth Day XXV reminds us that our hopes and intentions are not merely for abstract purposes. Indeed, they grant us a major role in detecting and monitoring environmental trends that may cause harm to life on this planet. We may come to serve as Earth's early warning system, or as the compass needed by leaders taking public policy in new directions. We can serve these and other purposes of value to humanity by making excellence in science routine.

Vincent Salomonson
director, Earth Sciences Directorate

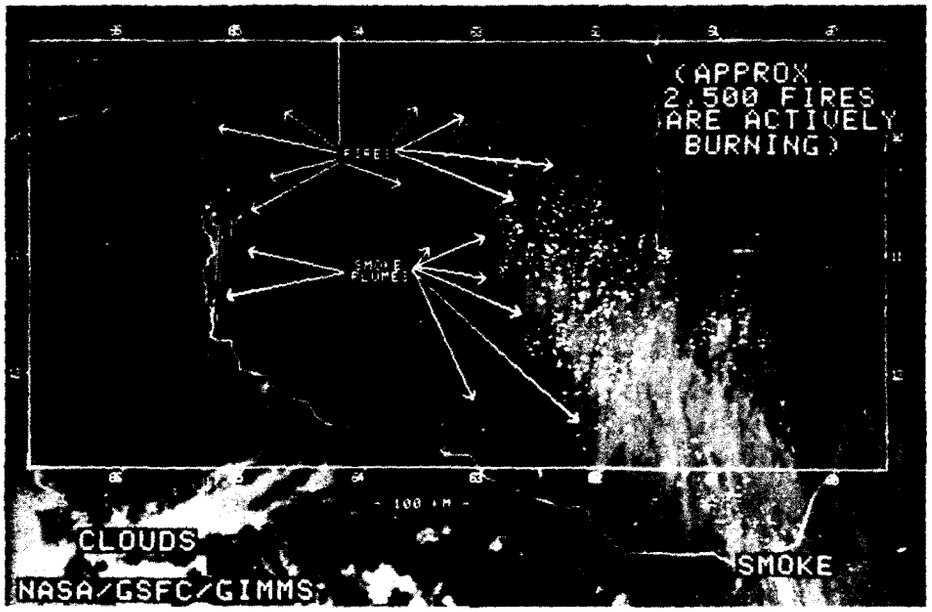
Earth is a sensitive, living system that responds slowly, but surely, to the treatment it receives. Human influences on the environment are now great enough to degrade it on a global scale, threatening Earth's beauty, the quality of our lives, and the biological systems that sustain the world's economy. NASA's Earth observing satellites will continue to play a vital role as sentinels of the environment. Their vantage point in space will provide the global view needed to cope with this global problem. They will help alert us to the need for decisions to address the environmental trends that portend harmful global change. I congratulate the employees, contractors, and colleagues of the Earth Sciences Directorate for their work as caretakers of Earth for future generations.

Senator Gaylord Nelson
Founder of Earth Day
March 31, 1995

A place with atmosphere

The life-sustaining mix of gases in which we live our lives is in constant change due to natural and human insults such as volcanic eruptions and auto exhaust. We do not know the limits of loading the atmosphere with pollutants, nor do we fully understand the potential effects of contaminants that might cause global warming.

We study our complex atmosphere using NASA technology and space observations, seeking to unravel the mysteries of its structure, dynamics, and chemical and radiative properties. The research includes atmospheric measurements and modeling of trace gases, winds, temperatures, clouds, rain, and aerosols on local and global scales. The following describe activities in areas that can affect health, safety and quality of life.

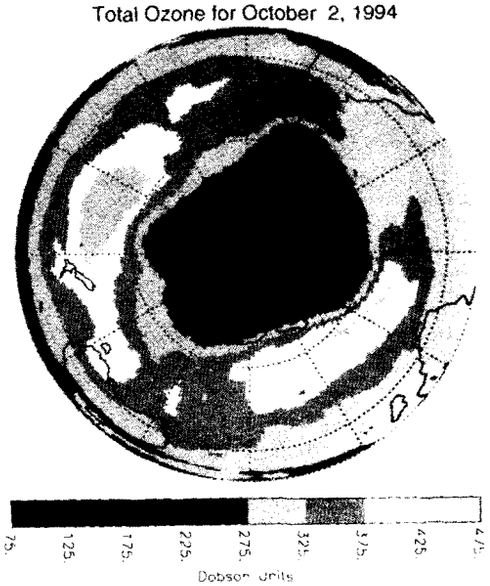


1,500 fires are burning in this image of Rondonia, Brazil, spreading smoke over thousands of square miles. Data for this image came from the AVHRR instrument onboard the NOAA-9 spacecraft.

The Missing Ozone

The Antarctic ozone "hole" is really a large-scale decrease in the amount of ozone over the South Pole that appears each year from August to October. Dr. Joe Farman of the British Antarctic Survey first noticed the drop in ozone levels in 1985 at Halley Bay, Antarctica, using a ground instrument known as a Dobson Spectrophotometer. Since then, Goddard scientists have used satellite data from the Nimbus-7 Total Ozone Mapping Spectrometer and other instruments to confirm Dr. Farman's findings and to try to explain the phenomenon. The ozone hole is now understood to result from manufactured chemicals. The extremely cold temperatures in Antarctica's lower stratosphere (where ozone exists) cause polar stratospheric clouds to form. As the sun rises over Antarctica, between August and October, chemical reactions on the surfaces of the clouds' particles release highly reactive chlorine compounds that cause massive ozone losses. Around October, as temperatures begin to rise, the clouds disappear, and ozone levels begin to return to normal.

Total Ozone for October 2, 1994



Fire and Smoke

Remote sensing of fires by satellite-borne instruments is a major tool in monitoring forest and savanna burning in the tropics, and in determining burn scars, the rate of deforestation, and the emission and transport of smoke. Population growth in the tropics has greatly increased the use of fire to fertilize soil, clear forested land for agriculture, and burn savanna grasses too thick for use as pasture. The smoke contains significantly higher amounts of greenhouse gases (e.g. methane and carbon dioxide) than are found normally in the atmosphere.

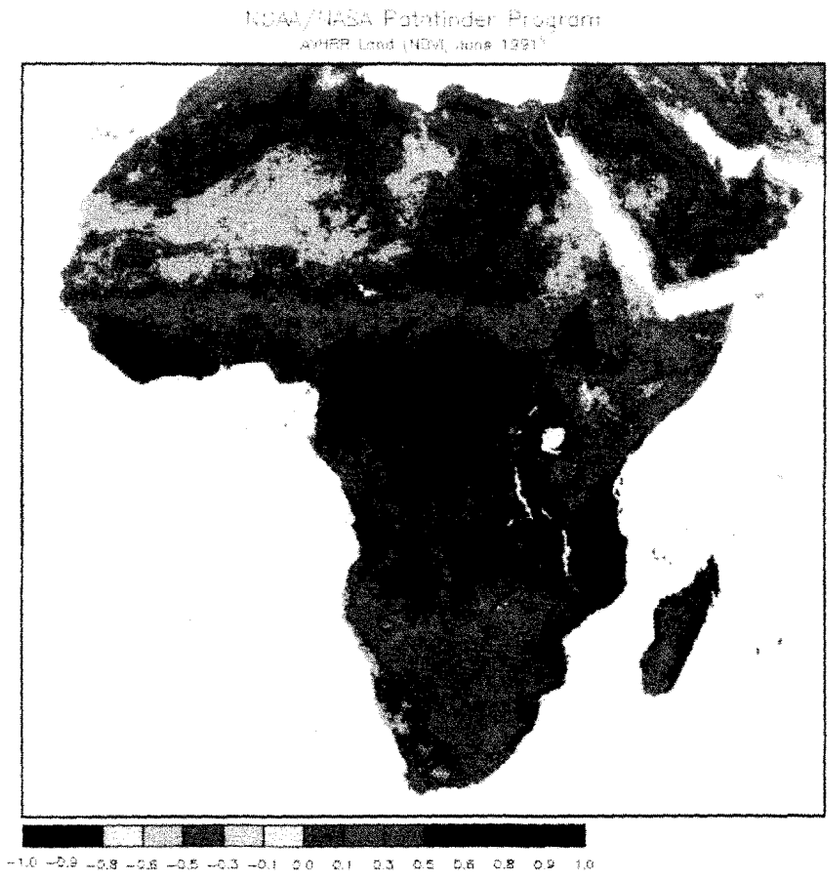
In the Amazon, soot particles carried in smoke can fill hundreds of thousands of square miles, polluting the environment every bit as much as factory emissions in Europe and the U.S., with the same associated health and environmental damage. The burning also destroys environments needed by tropical species and reduces oxygen-producing vegetation. With the launch of the Earth Observing System, the fire and smoke detection capability will be significantly improved.

Deadliest Hurricane Since the '70s

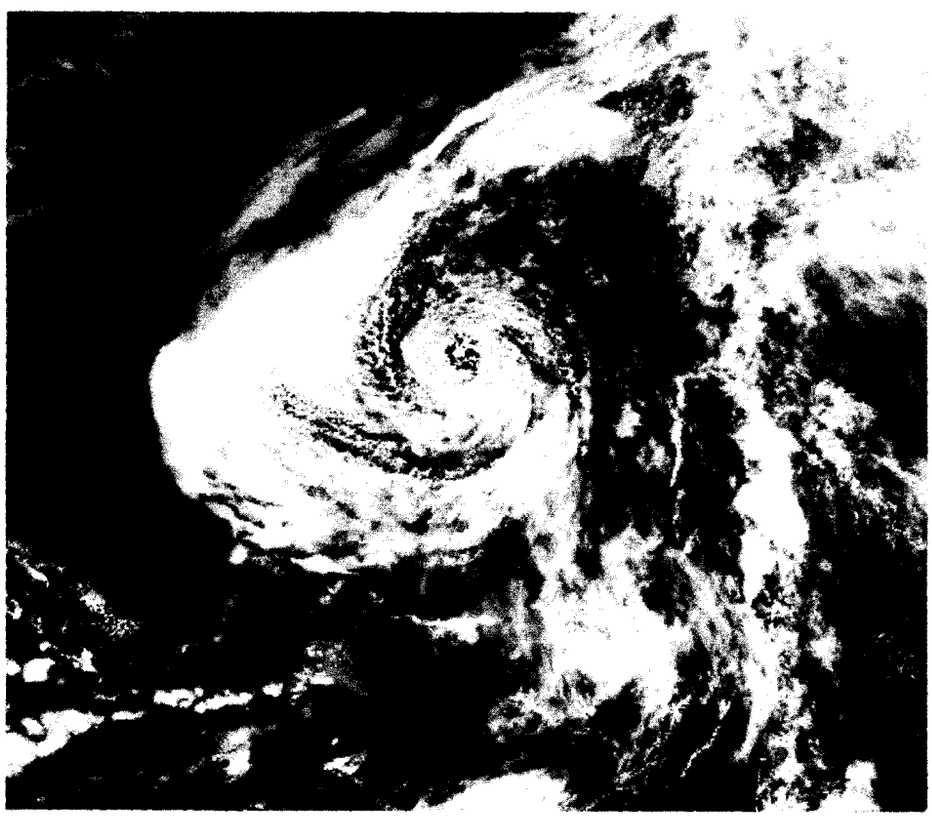
Hurricane warnings, vital for evacuating people and limiting damage, have become routinely effective due to weather satellites. However, some storms are so violent that casualties are high. Last November, the geostationary satellite GOES-8, viewed Hurricane Gordon as it pounded the Caribbean Sea, Florida, and U.S. East Coast. About 2,000 people were killed in Haiti due to flooding and mudslides, making Gordon the deadliest Atlantic tropical cyclone since 1979.

The Laboratory for Atmospheres, Code 910, performs theoretical and experimental research to:

- Advance the understanding of Earth's atmosphere: dynamics, energetics, radiation, chemistry
- Predict changes in habitability: weather, climate, ozone



Vegetation data of the African continent; the darker areas represent greatest concentration of vegetation and the lighter areas, the least.



Hurricane Gordon, as viewed by the GOES-8 satellite, November 1994.

Providing data to users

Acting alone, no nation has the resources to develop a predictive model of global environmental change. The enormous task of continuously acquiring, archiving, and analyzing data from satellite observations requires the collective talent and resources of the worldwide Earth sciences community. NASA is responsible for a portion of the global change information base. It manages data sources, holdings, and products of the Earth Observing System (EOS) under a Data and Information System (DIS). The management concept of EOSDIS ensures that data will be available to the user community indefinitely in an easily usable form, and promotes public access to archive centers where specific data are kept. Ours is called the GDAAC, for Goddard Distributed Active Archive Center.

Part of the Global Change Data Center (GCDC), it provides data and information at low cost to scientists and educators for studying long term changes in the global biosphere, the atmosphere, and upper atmosphere chemistry. Researchers can get data to study ozone depletion, greenhouse global warming, El Niño's effect on weather and climate, the impact of volcanic eruptions on ozone concentration, or the role of oceans, deforestation, and desertification in climate change. That's just for now. This year the GDAAC will also archive data from the upcoming EOS and Earth Probe series of satellites. To see what's currently available, order data online, or learn more about other DAACs or the GCDC, open the GDAAC's World Wide Web home page at http://daac.gsfc.nasa.gov/ and look around.

The Global Change Data Center, Code 902, supports the U.S. Global Change Program and the NASA Mission to Planet Earth by:

- Developing and operating data systems
- Generating science products
- Providing archival and distribution services for Earth science data to support research, education, and public policy

Physics of the Earth

Exciting research is underway at Goddard in the physics of Earth's structure, gravity, rotation, plate tectonics, magnetic fields, and biosphere, using data from spacecraft, aircraft, and ground-truth experimental studies. Some examples follow.

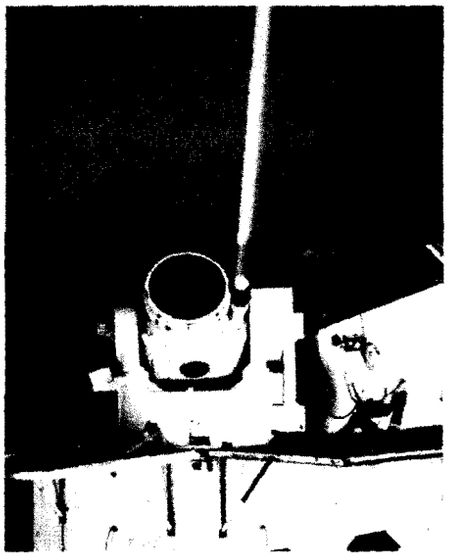


Figure 1. Ground-based laser

Global Positioning Technology

Today's satellite technology can locate your car or sailboat to within an inch of its true location. Artificial satellites are tracked using signals that they transmit or receive, or that are bounced off of them by radar or lasers (Figure 1). These signals help scientists calculate the orbits as well as the positions and movement of the tracking stations, while gaining a wealth of scientific information about the rotation and orientation of the Earth in space, its gravity field, tides, and crustal movement. By knowing within inches the position of instruments in space, oceanographers can use satellites such as TOPEX/Poseidon to map the shape of the ocean surface, and to learn about currents, tides, and changes in circulation that affect the weather worldwide (e.g., El Niño). By repeatedly finding the position of tracking stations with great accuracy, it is possible to follow the slow deformations of the Earth's crust, and calculate how stresses accumulate, raising mountains and causing volcanic eruptions and large earthquakes.

Assessing Earthquake Hazards

Field observations in Alaska using space-based technology help us learn more about the interior of the earth and mitigate the hazards of earthquakes. The most destructive earthquakes occur as a part of a process that is unique to our planet — the slow but continuous collision of tectonic plates. For example, in southern Alaska the Pacific Plate slides under or subducts beneath the North American Plate thereby generating large earthquakes.

In June 1993 precise position measurements were made in southern Alaska using the Global Positioning System. These measurements were used to determine the movements of the crust since a massive earthquake near Anchorage in 1964 and three large earthquakes in the Gulf of Alaska in 1988–89. This work continues this summer when NASA scientists and students and faculty from Alaskan high schools and universities will be making further observations.

Looking With Lidar

Water vapor and aerosols are important constituents within the atmosphere. Water vapor affects the development of clouds and our day-to-day weather as well as plays a crucial role in the study of man's impact on climate. Aerosols, which are particles suspended in the air, also affect the Earth's climate by scattering incoming sunlight. Goddard scientists are measuring water vapor and aerosols within the atmosphere using remote sensing techniques. With a Scanning Raman Lidar, scientists use a laser to send intense pulses of light into the atmosphere and measure the light scattered by water vapor and aerosols within the atmosphere. From the measurements of the scattered light, the amount and distribution of these important atmospheric constituents can be obtained with high accuracy. These measurements are used by scientists studying weather systems, atmospheric radiation, and climate modeling.

BOREAS

BOREAS, the Greek God of the north wind, inspired the name "Aurora Borealis," for the northern lights, and gave rise to the moniker "boreal," the vast conifer and aspen forests girdling the Earth above 48 degrees north. Now comes BOREAS, the project, also a namesake of this Greek legend. A Goddard-led project, it will study these vast forests to better understand their role in global change. To conduct this study, our scientists coordinated ground, aircraft, and satellite field campaigns in central Canada during 1994, leading an international, interdisciplinary team of more than 300 scientists. As shown in Figure 2, BOREAS employed a multiscale experiment design permitting physiological, ecological, and other data obtained at the leaf and canopy level, to be transferred to regional and even global scales using biosphere/atmosphere models and satellite remote sensing. Even at this early stage, a fascinating new picture is emerging. Despite the wet, soggy nature of the boreal soils, the atmosphere above is desiccated; humidity and deep boundary layer convection mimic conditions found only over deserts. Physiological

Continued on page 5

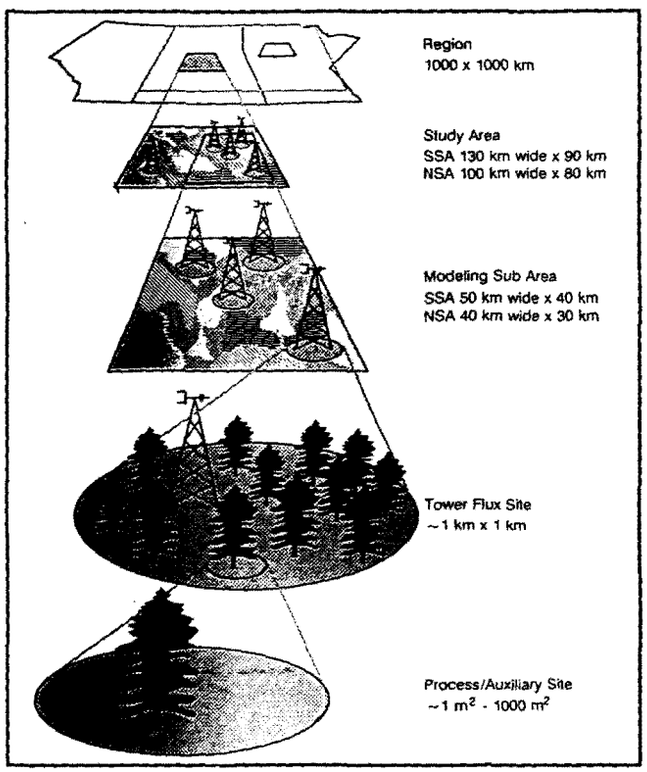


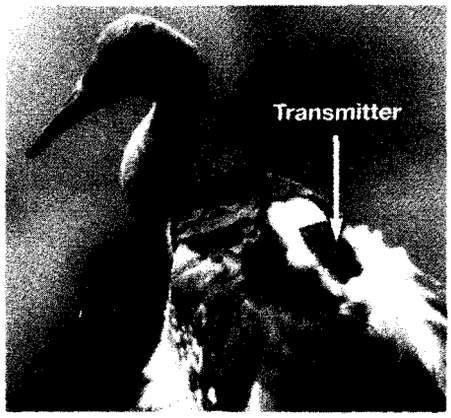
Figure 2. Multiscale measurement strategy in BOREAS

Computing helps capture a living planet

"Earth science data captures the heartbeat of a living planet, with each beat corresponding to a season or an annual cycle. Our planet is best studied in a three-dimensional, dynamically animated medium, one made possible by our supercomputers, high speed networks, science visualization techniques, and information management tools," said Dr. Milton Halem, chief of the Space Data and Computing Division (SDCD).

Over 1,000 U.S. scientists use Goddard supercomputers to develop Earth system models. The SDCD has created networks and transparent interfaces so that scientists can have direct access to our visualization tools and display their results at their own remote locations. Halem added, "The information has a universal quality, as with music or art, being appreciated at different levels by the science community or by the public."

To aid researchers in gaining further insight from images, SDCD scientists are developing virtual reality techniques offering high resolution stereo displays, and adding a precision tracking system that allows users to "get inside" their data. In addition, specialized software creates geographically gridded two and three dimensional imagery, providing a particularly useful medium for Earth science research.



Bugle, a Siberian Crane is among the migratory birds being monitored in an SDCD-National Biological Service collaboration.

Visualization also plays a key role in Earth science education, such as Vice President Gore's environmental monitoring program, Global Learning and Observation to Benefit the Environment (GLOBE). Students worldwide will measure environmental data and post their findings to the World Wide Web. Our visualization specialists have automated a system that plots and colorizes the data into three-dimensional visualization for World Wide Web access, viewing, and study.

Combining public education and wildlife protection, SDCD information scientists and the National Biological Service cooperate in a satellite monitoring program which tracks endangered species along migration routes, with special emphasis on birds. Some threatened species are being introduced to new migratory routes and stopover areas.

For more information on the program, open the SDCD's World Wide Web page at http://sdcd.gsfc.nasa.gov/SDCD.html.

The Space Data and Computing Division, Code 930, enables NASA-supported scientists to increase their understanding of Earth through the computational use of spaceborne observations and computer modeling by providing access to the following:

- High-performance computing
- Mass storage technologies
- Advanced information systems
- Computational science expertise

This image of the Earth was created in the SDCD virtual reality laboratory. The band circling the Earth represents the hottest regions of the atmosphere.

Physics

Continued from page 4.

measurements show that this desiccation is a result of the forest's strong biological control, limiting surface evaporation. Other data show this tight control to be linked to the low soil temperatures and subsequently reduced rates of photosynthesis. These and later findings should have significant implications for our understanding of how this important ecosystem impacts climate and other global processes.

The Laboratory for Terrestrial Physics, Code 920, performs theoretical, experimental, and modeling research in Earth science in:

- Gravity, topography, and magnetic fields
- Plate tectonics, crustal deformation, and structure
- Biosphere processes
- Interaction of vegetation with the atmosphere
- Altimetric oceanography
- Instrument technology

Examining Earth's oceans, ice, and land hydrology

Hydrospheric processes cover a broad range of research activities in oceanography, glaciology, and hydrology. Scientists plan and carry out satellite missions, create and use numerical models, compile and distribute major data sets, analyze data for information about global and regional changes and participate in field expeditions to such diverse places as Oklahoma, Botswana, and the ice sheets of Greenland and Antarctica.

Satellite Observations

Scientists use satellite data to obtain a better understanding of the global ocean/ice/water system: ocean color data to reveal near-global phytoplankton distributions; radar altimetry data to reveal near-global ocean topography and circulation, plus the topography of portions of the Antarctic and Greenland ice sheets; synthetic aperture radar data to map the Greenland ice sheet and discover a previously unknown ice stream in the midst of the ice sheet; and microwave radiometer data to determine the seasonal cycle and interannual variations in sea surface temperatures, snow coverage over the North American and Eurasian continents, and sea ice coverage in the north and south polar regions.

Conversion of the satellite data into valuable information about the Earth is a challenging and exciting activity, and scientists are actively involved in improving techniques for satellite measurements and analysis. The accumulating satellite records are a continuing source of surprises and exciting new results, as well as cautions against jumping too quickly to broad-based conclusions.

The Simultaneous View

Focused field experiments make use of simultaneous satellite, aircraft, and *in situ* observations. The results can improve our understanding of natural phenomena and processes. Satellite observations of Earth's hydrosphere can be calibrated and validated against measurements taken in the field.

There is a wide range of science disciplines involved. Biological oceanographers study the interaction between oceanic plankton and ocean circulation in the north Atlantic Ocean and the equatorial Pacific Ocean. Physical oceanographers study the coupling between the ocean and atmosphere in the western tropical Pacific. This is the warmest part of the global ocean and is thought important for phenomena such as El Nino (the periodic eastward displacement of the large warm pool of water in the western equatorial Pacific) and perturbations to global climate. Cryospheric scientists endure harsh environmental conditions on the ice sheets of Greenland and Antarctica to measure directly the changes in ice volume and stability. The data can improve our understanding of how these vast reservoirs of frozen water may affect global sea level. Hydrologists participate in multi aircraft campaigns coordinated with ground-based field experiments to gain insight to the cycling of water between the soil, vegetation, and the atmosphere. This was recently done for watersheds in Pennsylvania and Oklahoma, as well as in semi-arid regions of Africa.

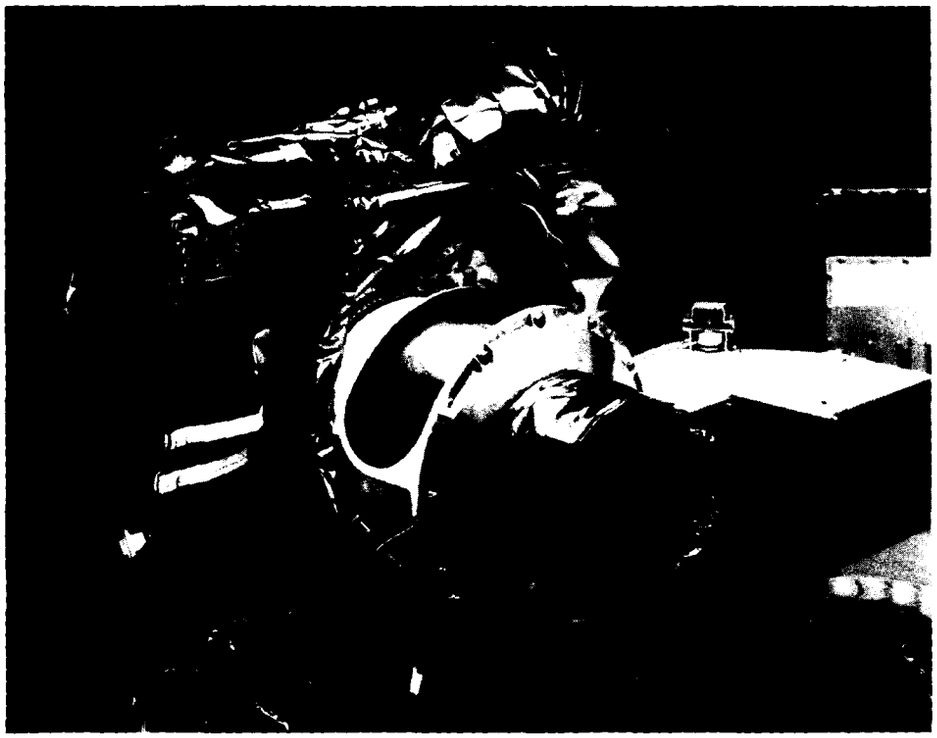
Modeling

Models varying in complexity and scale are used to understand and extract information on many phenomena. These include ocean circulation, interactions of the ocean and the atmosphere, and the effect on Earth's hydrological cycle of interactions between terrestrial moisture and the atmosphere. Computer simulations of hydrospheric processes help identify and isolate mechanisms important to the formation and maintenance of key phenomena and dynamics.

For large-scale ocean circulation, models can document the sensitivity of the circulation to changes in surface forcing by winds and heating/cooling. On smaller scales, surface wave generation models are used to help understand how momentum is imparted to the ocean by surface winds.

The Laboratory for Hydrospheric Processes, Code 970, performs theoretical, observational, and modeling research to:

- Understand the role of oceans and ice in global weather and climate
- Measure and analyze the abundance of water, ice, and snow on land surfaces and the exchange of water among the lithosphere, biosphere, and atmosphere.



The Sea Viewing Wide Field of View Sensor instrument will help to determine the role of the marine biosphere in the global carbon cycle. It will obtain ocean color data convertible to phytoplankton amounts, photosynthesis rates, and chemical exchanges between the ocean and the atmosphere.

Goddard Institute studies change

Based in New York City, the Goddard Institute for Space Studies (GISS) investigates global change — an interdisciplinary research activity that addresses natural and anthropogenic changes in Earth's environment, occurring on time scales of decades and affecting the habitability of our planet. A key research objective is prediction of atmospheric and climate changes in the early 21st century. The research combines analysis of comprehensive global data sets derived from spacecraft observations, with global models of atmospheric, land surface, and oceanic processes.

Global Climate Studies

Mathematical/computer models of the climate system provide a tool for studying climate interactions, analyzing past climate changes, and predicting future climate. GISS scientists are developing a General Circulation Model to simulate the climate on time scales of decades or more.

The increasing abundance of atmospheric carbon dioxide and trace gases may make the climate of the next century as different from today's climate as today's is from the last ice age, when a great ice sheet extended as far south as New York City. Climate models indicate that the 'greenhouse warming' due to these gases will become apparent early in the next millennium.

Cloud Studies

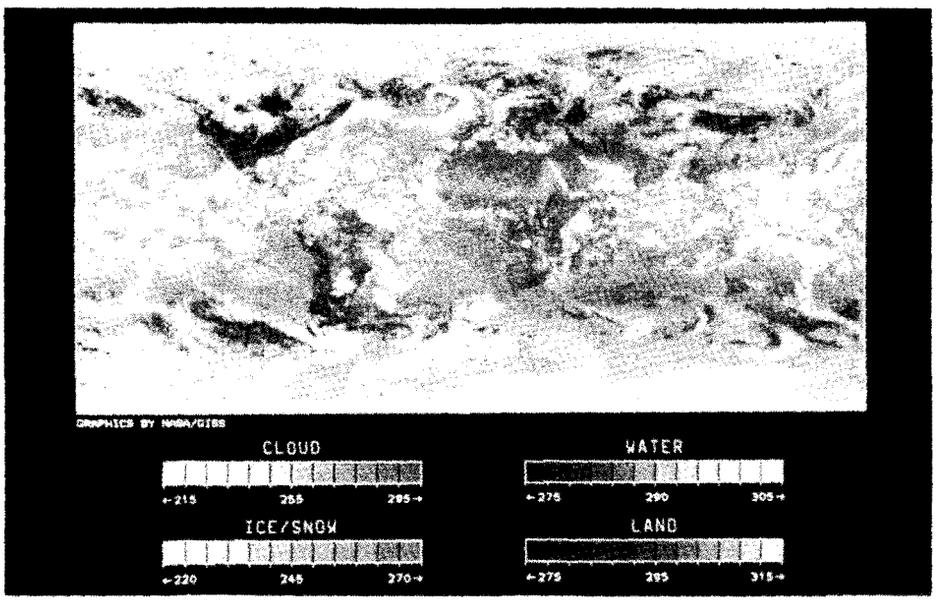
Water and ice clouds in Earth's atmosphere alter the exchange of energy from the Sun to the Earth and from the Earth to space, thus affecting the temperature of our environment. Clouds reflect more sunlight to space than do land and ocean surfaces, a process that suggests an increase in clouds should *cool* our environment. However, clouds are also colder and emit less heat radiation to space than does the surface, a process that would seem to cause increasing clouds to *warm* the environment. Which of these two effects will predominate in a changing climate is not known, but cloud variations have the potential to be one of the most important parts of our changing climate system. Clouds are also part of the cycle of water exchanges on Earth that determine the distribution of water needed for human activities.

Biochemical Cycles

Observations show that atmospheric carbon dioxide, nitrous oxide, methane, carbon monoxide, and chlorinated hydrocarbons are increasing. These gases are products of naturally occurring ecosystems, of geological cycling through soils and oceans, and of human activities in agriculture and industry.

Processes that cycle atmospheric trace gases and cause current atmospheric trends are being studied through three-dimensional chemical tracer models of the atmosphere and ocean. These models use data about winds, atmospheric structure, and convective transports from a general circulation model, natural exchanges of trace gases with oceanic and biospheric reservoirs, anthropogenic sources, and chemical losses in the atmosphere.

Model simulations can be compared with satellite and field observations to understand the current biogeochemical cycles, and predict the future composition of the atmosphere.



This illustration of the world cloud cover pattern on Oct. 15, 1983 provides an unprecedented view assembled from multiple satellite images made at infrared wavelengths in one hour. This kind of information enables Earth systems scientists to study the effects of global cloudiness on climate.

The Goddard Institute for Space Studies, Code 940, researches global change to:

- Understand the sources, sinks, and transformations of radiatively and chemically important trace gases in a changing climate
- Understand the causes of decadal climate change
- Produce climatologies of cloud, surface, and atmospheric properties

The prize

The new field of Earth Systems Science is piecing together the puzzle of the interrelationships and interactions among the Earth's land, sea, and atmosphere in order to preserve the environment of our Planet Earth, and to increase the science literacy of the population so that we all — scientists and the general public — work together to keep our planet vigorous and healthy.

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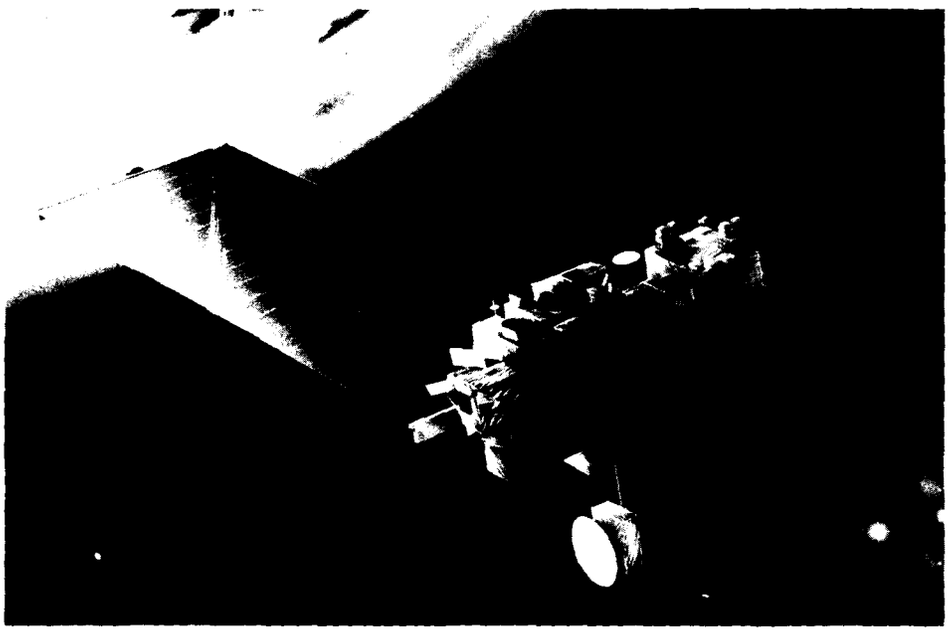
Keeping mother healthy

We have long thought of Mother Earth as a living entity. Nowadays, we worry about "Mom's" health. The interactions among the Earth's systems are as complex as those of the human body. Just as a doctor would use a physical exam to detect changes in a patient, NASA is using advanced technology to directly monitor the Earth's vital signs. The diagnostic tool is the Mission to Planet Earth (MTPE) program, with its Earth Observing System, which uses satellite, instrument, and computational technology to look into the oceans, land surfaces, and the atmosphere, and maintain a "medical history" of Earth's subsystems by monitoring the "patient" over many years.

Water, one subsystem, covers over 70% of the Earth, with only 1% liquid, fresh, and drinkable; the rest is tied up in polar ice masses and in salt-water oceans. Fresh water sources are replenished when water from the oceans evaporates into the atmosphere, forms clouds, then rains. The oceans hold plants and creatures important to life on this planet. They are vital to our existence, and must be kept healthy. Any change in their composition could affect the entire planet. Satellite measurements have shown that the level of the oceans has risen slightly. This rise could be due to higher ocean temperature, melting ice, or some other phenomenon. Only extended monitoring will tell us if this rise in water level is continuing, why it happens, how it affects other parts of the Earth, and its influence on our weather in persistent, yet ever-changing, ways.



When placed in orbit, the Earth Observing System (EOS) AM Spacecraft's sensors will provide detailed measurements of clouds, aerosols, and the land surface and will observe the interaction with the atmosphere through exchanges of energy, carbon, and water.

Another subsystem, the atmosphere, is equally complex after years of exploration, measurement, and observation, scientists are still discovering new and exciting phenomena. For example, the Upper Atmosphere Research Satellite recently confirmed that the layers of the atmosphere are mixing in such a way that the particles and gases in the lower atmosphere—many of them produced by industrial activities—have made their way up to the stratosphere. This mechanism transports man-made refrigerants, known as chlorofluorocarbons, to the stratosphere where they disrupt the Earth's protective ozone layer.

The oceans and the atmosphere are intimately related. An excellent example is the El Niño. Warm surface water off the South American Pacific coast affects global weather patterns, causing odd weather, including severe floods in California, changes in Atlantic hurricanes, and severe droughts. By understanding how the ocean and atmosphere interact, we can understand and accurately forecast changes in weather patterns.

Over the 15-year lifetime of MTPE, the combined current and future technology of satellites, instruments, and computational power will allow us to monitor the Earth's health continuously and develop policies for preventive medicine.

The Mission to Planet Earth Office, Code 170, supports and oversees efforts to:

- Determine the extent, causes, and consequences of global climate change in order to improve our understanding of the Earth as an integrated system
- Develop and apply the predictive capability needed to aid policymakers

Goddard News

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