Facilities to Empower Geosciences Discovery 2004–2008

National Science Foundation

National Science Foundation Directorate for Geosciences

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Foreword

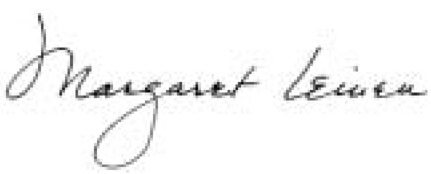
Facilities and instrumentation for observation, experimentation, analysis, and computation are essential to carry out frontier research in all fields of the geosciences. The provision of support for both the development of new and innovative facility capabilities, and the maintenance and enhancement of existing systems is an important priority for the Directorate for Geosciences (GEO) at the National Science Foundation (NSF).

This document, *Facilities to Empower Geosciences Discovery, 2004–2008,* complements the GEO Science Plan, *NSF Geosciences Beyond 2000 – Understanding and Predicting Earth's Environment and Habitability* (NSF 00-27). The capabilities described herein are intended to enable the aims in the Science Plan to be achieved.

Fundamental research in the geosciences requires a vast range of capabilities and instrumentation. GEO has engaged the community in a variety of long-range planning processes to evaluate opportunities and needs within the geosciences, and to determine the specific facilities, instrumentation, and capabilities that should be developed in support of the science. The planning and operation of these facilities relies strongly on close communication between GEO staff and the research community. Indeed, community-based workshops and meetings form the basis for all the major facility components described in this document. References to these community activities may be obtained from the specific programs.

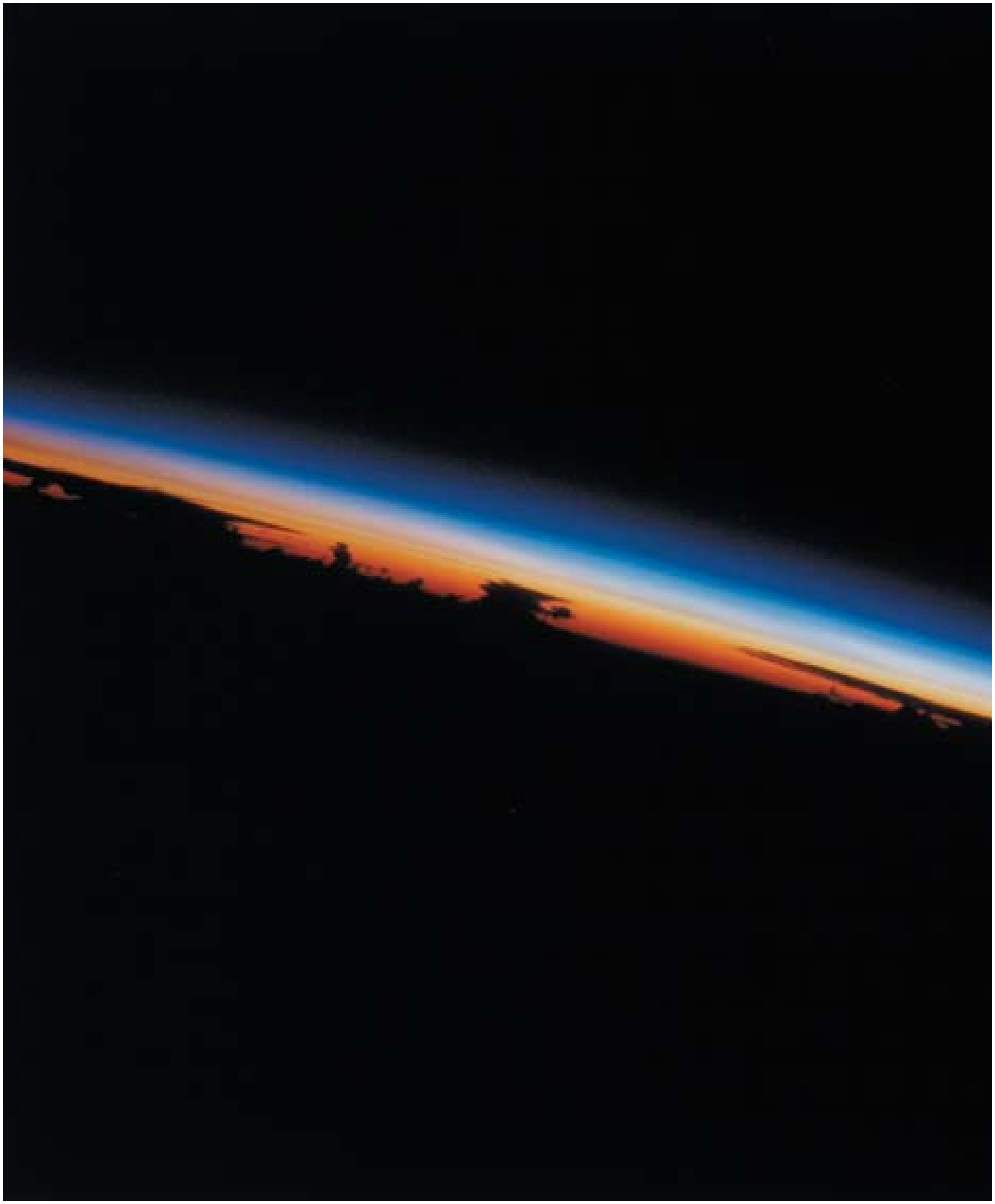
The active involvement of the research community in the GEO long-range planning process is also manifest in the active role taken by the Advisory Committee for Geosciences. Former and present members have contributed substantially to the Science Plan and to this report, which they have endorsed.

We wish to thank all those who have contributed to the document.



Margaret Leinen
Assistant Director for Geosciences

Joyce Penner
Chair, Advisory Committee for Geosciences



Earth's horizon, NASA.

Introduction

The vision of the Directorate for Geosciences (GEO) of the National Science Foundation (NSF) seeks to benefit the nation by advancing the scientific understanding of the integrated Earth systems through supporting high-quality research, improving geoscience education, and strengthening scientific capacity.

The Directorate strives to support creative people, scientifically challenging ideas, and essential tools to achieve success in meeting this goal. *NSF Geosciences Beyond 2000 – Understanding and Predicting Earth's Environment and Habitability* provides the comprehensive context for future activities and outlines specific Directorate objectives:

- Foster discovery and understanding of the factors that define and influence the Earth's environmental and planetary processes;
- Expand understanding and predictability of the complex interactive processes that
  - determine variability in the past, present and future states of planet Earth,
  - control the origin and current status of the forms of life on the planet,
  - affect the interdependencies of society and planetary processes;
- Provide the resulting scientific information in forms useful to society.

This document specifically addresses the essential facilities that have been identified to support the aims of the Directorate. It first outlines the current facilities for field and laboratory observations, sample collection, computation and data access, and education. It then provides a sequenced inventory of future elements that are planned for implementation as funding becomes available and appropriate proposals are considered and successfully reviewed.

The information has been assembled principally by the Directorate staff, based on frequent interactions with the scientific community and through community-based workshops and planning documents. It has benefited from frequent consultation with and review by the Advisory Committee for Geosciences.

The Facilities

Basic research and discovery in the Geosciences requires a vast range of capabilities and diverse instrumentation, including ships and aircraft, ground-based observatories, laboratory and experimental analysis instruments, computing capabilities, and real-time data and communication systems.

Many projects in the geosciences require extensive facilities and platforms to support the study of complex, interdependent processes that may extend from pole to pole. Comprehensive models of earth systems require significant investments in observational capability and computational systems demanding close coordination between the observational and modeling communities. Laboratory capabilities for study and analysis are also essential. The geoscience community relies on sharing access to samples and data for analysis of environmental processes. It pioneers new approaches to distribute information and develops new technologies to enhance our understanding.

The Directorate for Geosciences is firmly committed to the support of necessary infrastructure and facilities to support this important research enterprise.

All facilities supported by the Directorate must:

- Be driven by the basic research programs of NSF;
- Perform at the cutting edge of discovery, continuously evolving and improving services and capabilities;
- Have efficient and cost-effective management;
- Be well publicized with accessibility to the broad community;
- Share partnerships with operating institutions, private foundations, industry, other agencies, or other nations, as appropriate;
- Offer challenging educational opportunities.

This plan outlines the current integrated view of infrastructure fabric for geosciences, and notes the types of facilities and infrastructure currently supported by the Directorate. More significantly, it notes the strategic investments in facilities and infrastructure needed to enable the geoscience community to continue its pioneering research agenda. It focuses on the period 2004 to 2008.

Eruption of Mt. Etna, NASA.

An Integrated View of the Future

Several themes are expected to dominate the development of research capabilities over the next five to ten years.

Improved Technology: As technology advances our observing systems will improve. New technology will allow observing systems far more powerful, capable and adaptable than any of our present systems.

Integration Across Disciplines: Boundaries between disciplines are rapidly eroding as the community addresses the challenges of understanding the earth as an integrated system. Geoscience facilities must provide capabilities for integrated research across the boundaries of ocean, earth and atmospheric sciences, as well as related disciplines outside the traditional geosciences.

Continuing Exploration: As more sophisticated and long-term observing, data collecting, and analysis systems become available, appropriate priority and scheduling must be given to research facilities and infrastructure investments that expand the boundaries of current understanding.

NSF/NCAR C-130 aircraft.

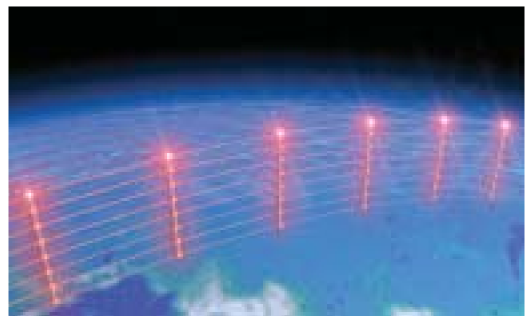
Alvin submersible, Woods Hole Oceanographic Institution.

The Access Revolution: A central trend in geoscience research is to increase the access investigators must have to under-explored regions (e.g., sea floor, Earth's interior, top of the atmosphere) through specialized research instrumentation.

Data Quality and Access: The need to maintain high standards of quality in the data collection systems and database construction is obvious. As users of large complex data sets become more widely dispersed it is increasingly important to develop practices and procedures ensuring the quality, accuracy, integrity, and availability of the data.

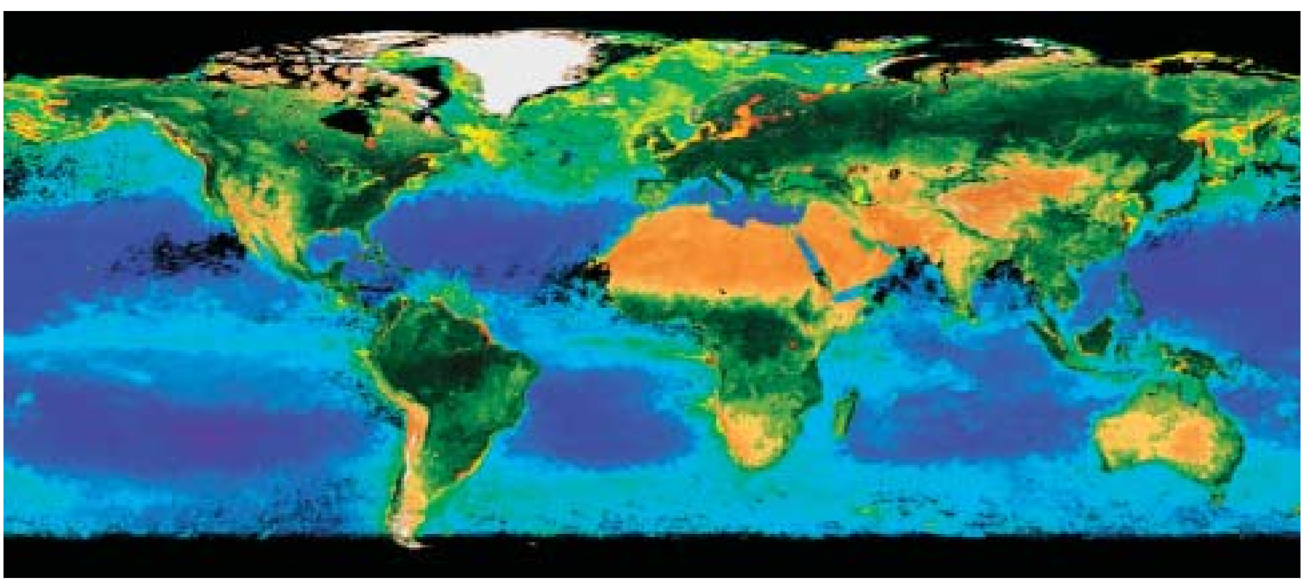
Observing Networks: As our understanding of the Earth's environment matures, our understanding and the needs of sophisticated data assimilation models depend more and more on networks of autonomous observational sensors, all connected via the Internet and accessible remotely.

Interagency and International Coordination: GEO supports facilities primarily because of their utility to NSF investigators, but in many cases these facilities are community-wide resources that receive support from multiple agencies or other countries.



Grids in 3-D climate model.

Earth's biosphere, Sea-viewing Wide-Field-of-View Sensor (SeaWiFS), NASA.



Current Infrastructure and Capability

Scientific advances in environmental and geoscience research require significant investments to maintain and upgrade existing observational and sample collection systems, laboratory and experimental systems, and computational and data access systems.

Existing Observational and Sample Collection Systems

Research Vessels and Other Ocean Platforms: A modern and efficiently operated fleet of oceanographic platforms is essential to support field programs for a diverse set of research projects from all fields of environmental and oceanographic sciences. These include ships, submersibles, fixed observatories and autonomous vehicles of all kinds.

Joides Resolution, *Ocean Drilling Program*.

Ocean Drilling Program: NSF provides most of the financial support of the *Joides Resolution*– the principal drilling vessel of the Ocean Drilling Program (ODP). ODP will complete its program in 2003 and plans are underway for a new program, the Integrated Ocean Drilling Program (IODP), involving international partnerships with Japan and European countries.

Research Aircraft and Airborne Instruments: Advancements in geosciences are inextricably linked to detailed *in-situ* and remote observations of the Earth system that can only be accomplished with specialized instrumentation flown on capable aircraft.

Naval Research Laboratory P-3 with Eldora radar.

Scientific Drilling on Continents: Drilling on the continents provides direct observations of active geological processes (e.g., mechanics of faulting, fluid circulation in hydrothermal systems, thermal and eruptive regimes of volcanic systems, models of geologic structure and stratigraphy, and the origin of mineral and hydrocarbon deposits). New drilling techniques (e.g., the DOSECC Hybrid Coring System) allow the sampling and emplacement of deep long-term observatories within dynamically active regions of the earth's crust.

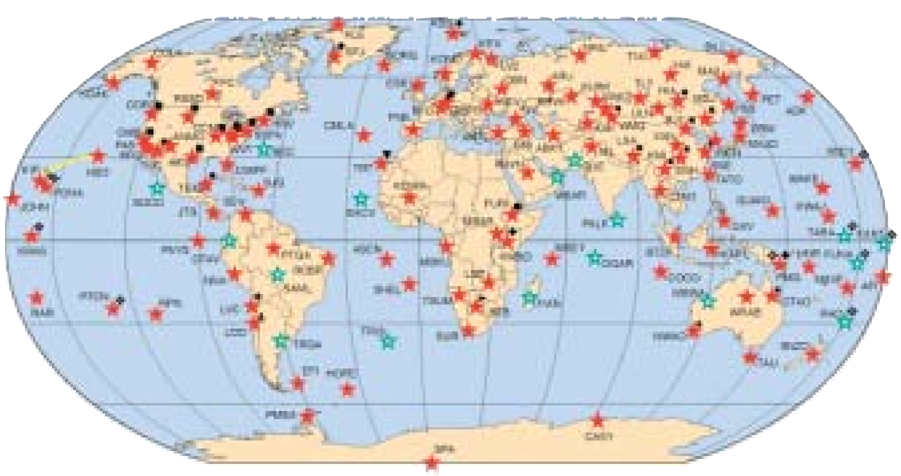
San Andreas fault, Shuttle Radar Topography Mission, NASA.

Global Lake Drilling-800 (GLAD 800): This drilling system is designed for the retrieval of long sedimentary records from the world's large and deep lakes. The drilling system is mounted on its own portable barge, has a depth range of 800 m, and features heave compensation and dynamic positioning.

The Global Seismographic Network (GSN): A network of broadband, digital seismic stations distributed globally to monitor earthquakes, underground nuclear explosions, volcanic activity, and to research deep earth structure. The GSN has now reached the number of instruments required to provide uniform global coverage of the continents and part of the oceans. Plans include station upgrades and replacements, enhancement of selected stations to 'geophysical observatories,' with addition of GPS receivers, magnetometers, gravimeters, and micro-barographs to form the nucleus of a multi-purpose geophysical network, continued improvements of telecommunication capabilities, and cooperation in the development of ocean bottom stations.

Seismic Instrumentation: A pool of portable seismometers for worldwide field deployment, including ocean-bottom seismic instruments. Plans include replacing key hardware components of the existing PASSCAL (Program for Array Seismic Studies of the Continental Lithosphere) inventory, increasing the existing instrument pool capacity, expanding the use of digital communications infrastructure to make it possible for researchers and educators to readily implement "virtual seismic networks," extending the capabilities of broadband arrays, and acquiring additional small, lightweight, inexpensive instruments, activated to record by radio command.

IRIS Global Seismographic Network (GSN). Red stations completed prior to 2000; blue completed after 2000; black are national and international cooperative sites.



Doppler radar installation.

Surface and Sounding Systems: *In-situ* and remote observations of the atmosphere from ground-based instruments are a staple of environmental measurement. These observing systems are portable and have the ability to measure several variables simultaneously using the latest technologies such as dual-polarization Doppler radar or GPS-equipped sensors. Taken together, these systems provide the community with accurate measurement for many atmospheric parameters and a better approximation of the state of the atmosphere.

Incoherent Scatter Radar Chain: The global chain of incoherent scatter radars, with facilities in Peru, Puerto Rico, Massachusetts and Greenland, provides a powerful and robust capability to measure the upper atmosphere and ionosphere. These key ground-based instruments, however, need to be upgraded to incorporate modern radar technology and complementary optical instrumentation. Plans include modernizing the aging transmitters at all the radar sites and installation of state-of-the-art optical sensors. The Arecibo Observatory also has plans to install a high power HF radar to conduct key plasma physics experiments and for ionospheric modification.

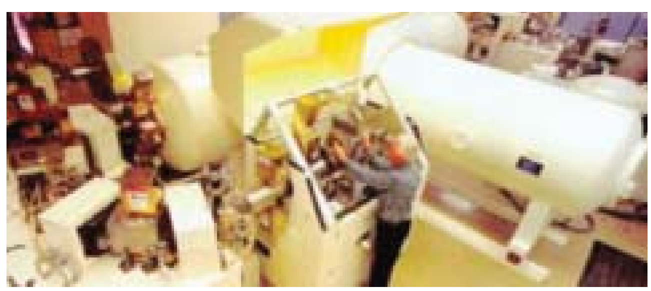
The Global Positioning System (GPS): The capability of determining global positions to high precision using GPS has spawned an explosion of applications in the geosciences, including the measurement of the rates of crustal deformation at the millimeter/year level. To keep pace with GPS applications in the geosciences, future plans include: enhanced support for both campaign and permanent GPS stations, and support for technological methods of improving the accuracy of GPS measurements, especially in the vertical dimension, using antenna and multipath calibration systems.

Global Positioning System (GPS) transceiver.

Laboratory and Experimental Systems

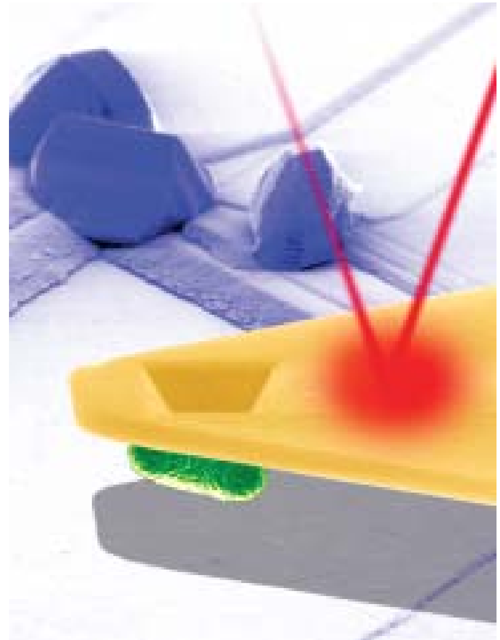
Modern laboratory instrumentation and experimental facilities are required to serve the needs of a large number of user communities.

Accelerator Mass Spectrometers (AMS): Three GEO-supported AMS facilities are used to measure isotope species with sensitivities of one part in 10^{14} or better, making it the only analytical tool available for radiocarbon dating of old or very small samples. Additional applications include the measurement of rare cosmogenically produced nuclides of aluminum and chlorine as chronometers of surficial processes and tracers of hydrologic pathways.



Accelerator Mass Spectrometer (AMS) at Woods Hole Oceanographic Institution.

Ion Microprobes: The ion microprobe is the instrument of choice for precise isotopic and trace element analysis combined with micron-scale spatial resolution. GEO supports two large-radius ion microprobe national facilities that focus on both geochronology (U-Th-Pb isotope analyses of accessory minerals) and stable isotope tracer studies (O and C isotope analyses). Applications include exploring solar/presolar materials and processes, early Earth evolution, mantle and crustal dynamics, climate change, environmental pathways, and experimental geochemistry.

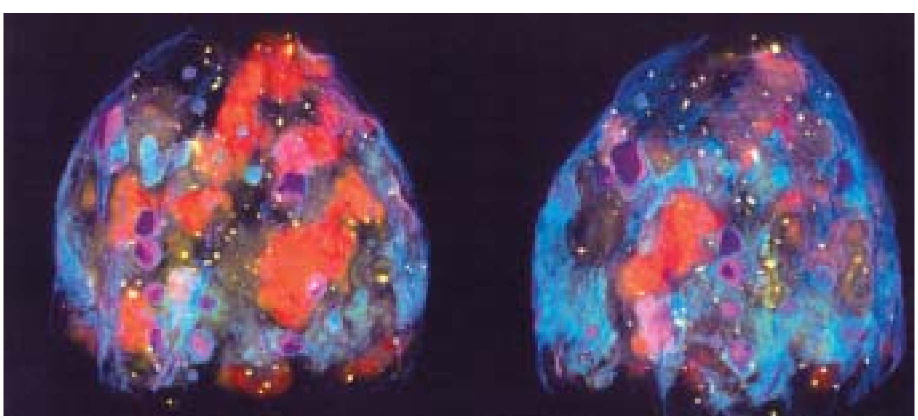


Composite Scanning Electron Microscope (SEM) image showing biological force microscopy (U. Maryland and Virginia Tech.)

Synchrotron Radiation Facilities: Synchrotron storage rings use magnets to bend or undulate relativistic electrons or positrons to produce x-ray beams of unprecedented brilliance and energy range. When combined with modern diffraction, spectroscopic and high pressure and temperature techniques (i.e., the laser heated diamond anvil cell), the result is an explosion of new tools for study of the physical and chemical properties of natural and man-made materials at the atomic-scale. GEO supports the construction, instrumentation and operation of the user-access beamline facilities at Argonne and Brookhaven laboratories.

Institute for Rock Magnetism (IRM): The study of magnetism in rocks and sediments contributes significantly to geoscience research on plate tectonics, mantle dynamics, origin and evolution of the Earth's magnetic field, the timing of sedimentary processes and paleo-environmental reconstruction. Detailed study of the magnetic properties and behavior of natural and man-made materials made possible by unique equipment at the IRM also has implications for improving the quality of magnetic media.

Facility for Computed X-ray Tomography: Permits completely non-destructive imaging of the interior of geological and biological samples. Rapidly imaged 3-D high resolution computer models of rare life forms and fossils, petrologic samples and man-made materials allows for unprecedented views of the interior structure of vertebrate and invertebrate fossils, rocks and materials without time-consuming and painstaking preparatory work inherent in standard sectioning techniques.

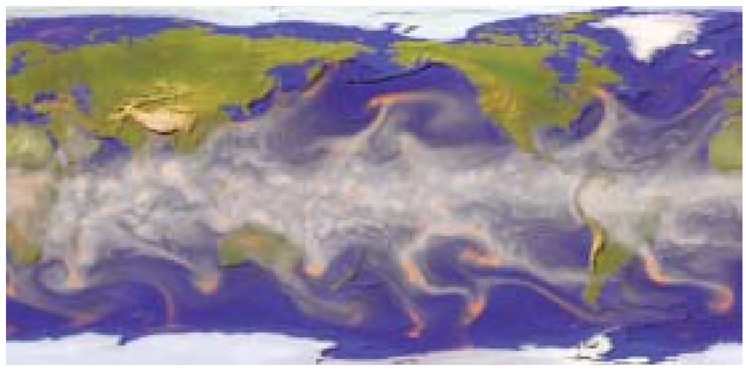


Three-dimensional reconstructions from high-resolution X-ray computed tomography of diamondiferous eclogite from Russia (U. Texas and U. Tennessee).

Computational and Data Access Systems

Large data sets produced by modern geoscience instrumentation or computation require modern computing equipment for acquisition, archiving, distribution and analysis. Convenient access to sample collections and large digital data sets is essential to many research programs in the geosciences and requires the creation and maintenance of data management systems and sample archive facilities

Climate Simulation Laboratory: This multi-agency United States Climate Change Science Program provides high performance computing, data storage, and data analysis systems to support large, long-running simulations of Earth's climate system. Research advances in computer models has lead to increased model veracity and complexity. To maintain progress, a substantial increase in computational resources will be required.



Climate simulation from NCAR Community Climate Model, version 3 (CCM3).

The IRIS Data Management System (DMS): Provides global access to the central archive for seismic data collected by the Global Seismographic Network (GSN) and field experiments and the software tools to enable studies of the Earth's deep interior, earthquake processes, volcanic plumbing systems and anthropogenic seismicity including underground, undersea and surface detonations. The IRIS DMS also serves as a data resource for much of the seismology community's education and outreach efforts.

Sonic anemometers installed at Utah elementary school (U. Utah).

Sample Collections: Chemical, biological, and geological samples from specific research studies often retain value following the initial study. Examples include biological culture centers, geological samples from the Ocean Drilling Program and other field studies, photographic archives from deep submersible science studies, a number of marine biology collections, and sediment and rock cores recovered from lake and continental drilling.

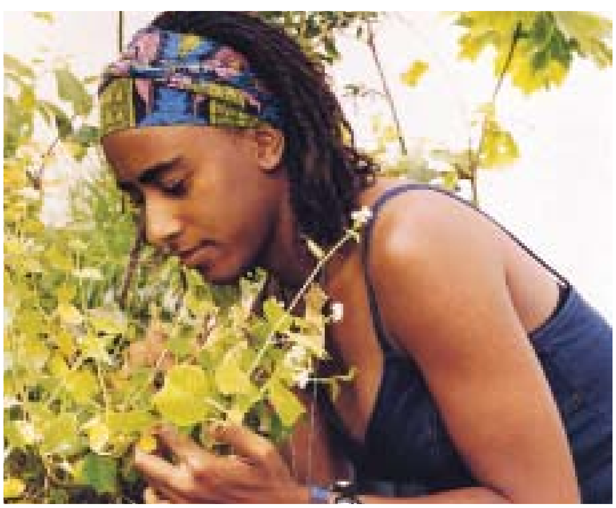
Unidata: Unidata offers software and services that enable atmospheric scientists to acquire and use an extensive array of data products, often in real time, through a nationwide network of researchers with common interests in atmospheric and related sciences and shared needs for data and software. In the coming years, Unidata will focus their development and services efforts on improving delivery of real-time data flows, superior visualization and analysis software, better methods for the distribution of digital information, enhanced capabilities in computer augmented discourse and discovery, and broadening the communities served.

Facilities and Education

Many GEO-sponsored facilities, while having primarily a research-driven mission, also have ambitious education and outreach programs in place and under development. These programs typically reflect the missions of the facilities, yet are designed for broad impact at multiple educational levels: graduate and postdoctoral, undergraduate, pre-college, and public outreach.

Facilities Programs: Expanded support is planned for the following facilities:

- The University Corporation for Atmospheric Research (UCAR): UCAR supports a large number of educational programs aimed at the full range of education levels, including public outreach. These capitalize on interests in atmospheric science phenomena.
- Incorporated Research Institutions for Seismology (IRIS): IRIS has established an education and outreach program aimed at using the excitement of seismology and related geosciences as a stimulus for improving science education at all levels.
- Integrated Ocean Drilling Program (IODP): The program will establish a broad range of educational activities at all levels, includes students on cruises, and develops public outreach and educational materials.
- The Academic Research Fleet: GEO provides the major funding support for the US academic research fleet. Institutions with NSF-supported vessels provide numerous opportunities for student experiences as well as opportunities for the wider community to benefit from research activities through public outreach and educational material development.



A protégé of the Significant Opportunities in Atmospheric Research and Science (SOARS) program at UCAR.

Proposed new ice-capable Alaska Region Research Vessel for multidisciplinary research, Glosten Associates, Inc. and the University of Alaska, Fairbanks

New Capabilities and Capital Investments

Scientific breakthroughs or technological advances drive demands from the research community, and GEO seeks to enable investigators by providing new state-of-the-art capabilities in a timely way. NSF's Major Research Equipment and Facilities Construction (MREFC) account is enabling the acquisition of more costly items. GEO is addressing more modest requirements as funds become available. The following sections describe current or approved MREFC funded projects and near-term facilities and infrastructure actively under consideration. Out-year elements are identified for long-range planning purposes.

Supported by the Major Research Equipment and Facilities Construction Account

High performance Instrumented Airborne Platform for Environmental Research (HIAPER): HIAPER is a modern, high-altitude, long-duration aircraft to be outfitted with new sensors, data acquisition systems and scientist workstations to accommodate scientific investigations. The mid-sized aircraft is a Gulfstream G500 jet, having the capability to reach 51,000 feet with a flight duration of 12 or more hours depending upon the instrument payload. This combination provides a unique capability to the atmospheric and other earth scientists. The basic airframe is completed and structural modifications have begun. Operation is expected to begin in late FY2005.

High performance Instrumented Airborne Platform for Environmental Research schematic.

International Ocean Drilling Program: NSF currently provides most of the financial support of the *JOIDES Resolution* - the drilling vessel of the Ocean Drilling Program (ODP). ODP will complete its final drilling program in September 2003. A new phase of international scientific ocean drilling, the Integrated Ocean Drilling Program (IODP), will begin in 2004, co-led by NSF and Japan. Japan will provide a heavy drill ship for deep crustal drilling and NSF will provide a light drilling ship, similar to the *JOIDES Resolution*, for paleoenvironmental, observatory, and biosphere studies. Significant scientific and financial participation is expected from Europe. NSF plans to convert a commercial drill ship to scientific capability for IODP with conversion funding from the MREFC account planned for 2005-2006.

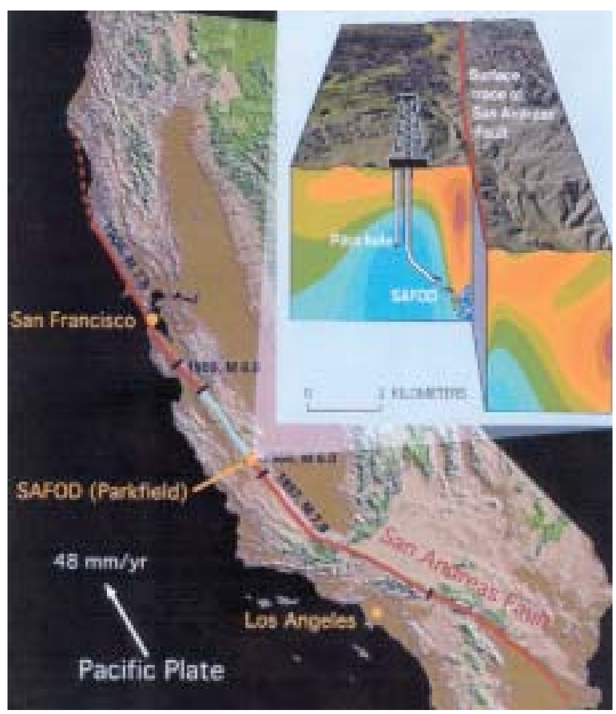
Schematic of Japanese drilling ship Chikyu.

EarthScope: The EarthScope facility is a multi-purpose array of geophysical and geodetic instruments and observatories that will greatly expand the observational capabilities of the Earth Sciences and permit us to increase our understanding of the structure, evolution and dynamics of the North American continent. EarthScope consists of:

- The Plate Boundary Observatory (PBO): The Plate Boundary Observatory is a continental-scale array of continuously recording GPS and strain meter systems that will enable unprecedented observations of deformation of the Earth's crust over a broad range of spatial and temporal scales.

- US Array: The US Array is an array of broadband and short-period seismometers that will provide a coherent 3-dimensional image of the structure of the entire continental U.S. and provide a foundation for thorough and systematic seismological-geophysical study of fault patterns at depth and the nature of the earth's crust and upper mantle.

- San Andreas Fault Observatory at Depth (SAFOD): SAFOD is a state-of-the-art in situ geophysical and geochemical observatory to examine the state, dynamics and geochemical parameters of a major active fault at 4 km depth. The US Geological Survey is a partner for SAFOD.



Schematic representation of the San Andreas Fault Observatory at Depth (SAFOD) borehole and pilot hole near Parkfield, CA.

◆ Interferometric Synthetic Aperture Radar (InSAR): Interferometry from repeat satellite radar images will give unprecedented detail of crustal distortion related to the movement of fluids, glaciers, magmatic systems (volcanoes) and tectonic forcing (earthquakes). NASA is the primary partner for InSAR.

The first three elements of EarthScope, the PBO, USArray and SAFOD, have been included in the NSF MREFC account. The fourth element, InSAR, is dependent on the NASA budgetary process. NSF participation in InSAR would be below the MREFC funding level threshold and would be supported as a mid-sized infrastructure initiative.

Ocean Observatories Initiative (OOI): Investigation of the oceans as a dynamic system requires sustained observational capabilities in remote locations not routinely accessible by ships. OOI has three components: 1) coastal (including Great Lakes) - with new or enhanced capabilities to existing observatories; 2) relocatable - based on a network of deep water moorings; and 3) regional - a fixed observatory encompassing several oceanographic features or processes comprised of a fiber-optic cable running to shore with multiple nodes or junction boxes to which scientific instruments may be attached. OOI is planned to be supported through the MREFC account.

Artist's rendition of elements of the Ocean Observatories Initiative (OOI).

Near-term

New Capabilities for Computational and Data Access Systems

High Performance Computing Capability: Challenges inherent in the computational components of research in atmospheric, ocean, and earth sciences require a capable computing facility (e.g., 3–5 Teraflops, sustained). Much GEO research involves the movement and analysis of large (and often disparate) data sets and so high-speed network access, data management, visualization and machine-learning-based data analysis tools are also required as part of this infrastructure. To make use of this technology requires the human infrastructure of software engineering, operations and programming support. These facilities would provide computational, analytical, data management, and collaborative services in support of research efforts in all areas of the geosciences.

IBM SP cluster at NCAR.

Climate science computational infrastructure: The forefront of climate research in particular requires significant computational and information science resources. The high-resolution global climate modeling anticipated over the next 3–5 years requires access to large-capability computing facilities that can sustain 5–10 Teraflops on a full climate model for periods of two to three months. The study of uncertainty in climate modeling similarly requires many runs at somewhat lower resolution and so requires capacity more than capability (e.g. dedicated use of one or more large scalar massively parallel processor (MPP) machines). The rise in regional climate modeling and studies of the regional impacts of climate variability pose a need for dispersed mid-sized computational infrastructure such as multi-node shared memory machines of moderate size and clusters such as Beowulf clusters operated by university research groups.

Computational Infrastructure for Geodynamics: Numerical modeling of the dynamics of the interior of the earth and planets is often the only method available to assess the physical basis for fundamental observation at the earth's surface including magnetic fields, transient deformations of the crust, mantle, and lithosphere due to glacial cycles and earthquakes, and even global seismic wave propagation. Scaled-down laboratory experiments can help to guide models and the models can further guide experiments, but most experiments require unrealistic scaling of important parameters. A distributed facility necessary to develop and maintain computational infrastructure for geodynamic modeling is envisioned. The facility would include hardware, technical personnel, senior-level numerical analysts and computational scientists, and a governing structure dedicated to modern software design, code validation, and user-friendly graphical interface development for the larger community of Earth and planetary scientists.

GeoInformatics: The geoscience community needs a web-accessible hierarchical network of Earth science data/information and knowledge nodes. The GeoInformatics system will include analysis, visualization and modeling and archival tools to drive the next generation dynamical modeling of earth systems, as well as education and public outreach.

Oceanographic Information Technology Infrastructure (OITI): New hardware to increase Central Processing Unit (CPU) cycles, memory, mass-storage, and network bandwidth; and new software systems to re-engineer model code for efficient use on massively parallel computers, to improve data visualization and to develop/document/test community models.

Observational, Experimental, or Sample Collection Systems

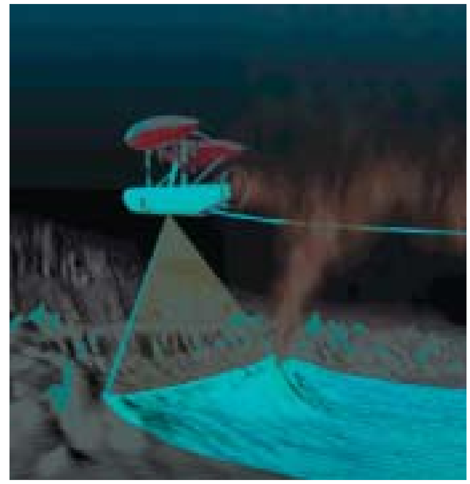
Advanced Modular Incoherent Scatter Radar (AMISR): A modern state-of-the-art facility for studying the properties of Earth's upper atmosphere and ionosphere. The observatory features a powerful phased array incoherent scatter radar, modern optical instruments and the capability of being rapidly disassembled and reassembled anywhere on the globe.

Schematic showing three faces of the Advanced Modular Incoherent Scatter Radar.

Distributed Facility for the Hydrological Sciences: A national facility for the advancement of the hydrological sciences to coordinate the full range of emerging technologies and computing resources to address research problems in hydrologic sciences.

- Long-Term Hydrologic Observatories (LTHO): A network of hydrologic research observatories for comprehensive, integrated measurement and analysis of hydrologic systems at all scales.
- Hydrologic Data Assimilation System (HDAS): To support the data, analysis and distributed modeling requirements of the hydrologic research community.
- Hydrologic Measurement Facility (HMF): To develop and operate state-of-the-art measurement systems and provide support services for hydrologic research.

Autonomous Ocean Platforms: A "fleet resource" of small, multi-disciplinary autonomous platforms (e.g., Autonomous Underwater Vehicles (AUV), gliders, floats, drifters) for deployment to investigate processes in regions not easily accessed by conventional research vessels.



Schematic swath from underwater autonomous vehicle.

Facility for Airborne Laser Mapping (ALSM): Access to airborne platform-based laser ranging systems capable of detailed regional mapping of the topography of Earth's surface is needed to advance research on processes effecting the earth's habitable surface. Laser swath mapping allows for the development of very high resolution Digital Elevation Models (DEM) of surface features including both landforms and the vegetative canopy. Centimeter accuracy DEM are needed as inputs to sophisticated models of landscape, hydrologic and cryosphere processes. Models based on these high resolution topographic data will allow for new insights into processes including floods, storm surges, landslides, volcanic eruptions, soil creep, erosion and glacial dynamics, that directly influence human activities. ALSM can provide topographic data at scales appropriate to the scale at which many of these processes operate.

Distributed National Facilities for Geochronology: The Geoscience community is pressing the limits of its ability to accurately and sufficiently measure the rates and processes that have shaped the development of the Earth. The next generation of cutting-edge geoscience, such as that initiated by EarthScope, requires higher precision and more detailed geochronology data than can be provided by the present laboratories. Thus, a national facility of distributed geochronology centers needs to be developed. Additional research infrastructure may also be needed in the area of high-precision isotopic fingerprinting of biogeochemical processes using stable isotope geochemistry.

New Manned Submersible: Alvin, the national facility operated by Woods Hole Oceanographic Institution is now well over 30 years old and has been the most scientifically successful submersible in the world. There is a great need to replace it with a larger, deeper-diving, technologically advanced successor.

Artist's conception of a new Alvin.

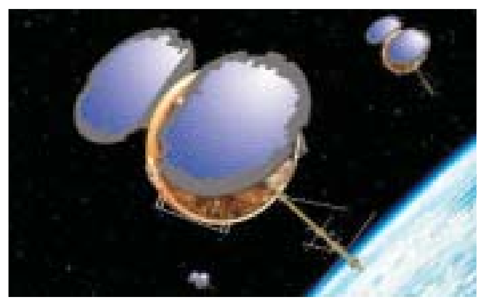
Doppler radar on wheels, NCAR.

Airborne and Ground Based-Mobile Atmospheric Observing Instrumentation and Facilities: Research requires advanced mobile airborne and ground observing instruments and facilities that may be easily deployed during field campaigns (e.g., Doppler radar on wheels). With the continued advances of emerging technologies (e.g., adaptive optics, phased arrays, communications, and data display technologies) platform lifetimes significantly exceed that of instrumentation and supporting infrastructure.

New Instrumentation for Global Upper Atmospheric Observations: Emerging priorities in upper atmospheric research emphasize the need for global observations of the upper atmosphere using robust and easily deployable ground-based instrumentation. These include new generation lidars capable of probing the mesosphere and lower thermosphere; small, inexpensive Fabry-Perot interferometers for neutral wind measurements; strategically arrayed magnetometers to detect ionospheric currents; and compact radar systems that can run continuously and provide height-resolved measurements of atmospheric parameters. A portable observatory with a suite of such instruments could be easily deployed in conjunction with the Advanced Modular Incoherent Scatter Radar.

Research Vessel Renewal: The current academic fleet is aging and needs replacement. The Federal Oceanographic Facilities Committee (FOFC) issued a report in December 2001 defining a federal interagency renewal strategy for the national academic research fleet over a period of about 20 years. Of the ships listed in the FOFC plan, the Alaska Region Research Vessel (ARRV) is of highest priority for NSF funding. NSF is also developing plans to support the concept design and construction of the Regional Class ships described in the FOFC plan beginning with a ship for the Gulf of Mexico followed by ships for the Pacific and Atlantic. Tentative plans are to build 3 Regional Class ships in 6 years with construction funds available beginning in FY06.

Satellite Receiving and Distribution Center: An advanced data acquisition and distribution center (including satellite data) for near real-time collection and distribution of routine and experimental atmospheric observations (e.g. satellite radio occultation profiles) of atmospheric variables for use in advanced modeling and observational programs in the atmospheric sciences.



Artist's depiction of the Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC) satellite constellation

Remotely Piloted Aircraft (RPA): RPA technology is now reaching the maturity where it is feasible to do very long duration missions (i.e., 48 hours) at an impressive range of altitudes and locations. Large payload aircraft such as the DARPA-developed Global Hawk would provide the research community with research opportunities that cannot be accomplished with piloted aircraft. Alternatively, small Unmanned Aerial Vehicle (UAV) systems instrumented with multi-element arrays of miniaturized chemical sensors or optical detectors, for example, and equipped with advanced communication and control systems could uniquely probe highly variable remote atmospheric regions. Their incorporation into science programs will be influenced by the regulatory climate.

Storm Penetration Aircraft (SPA): *In situ* measurements within convective storms require a specialized airborne platform. Currently NSF supports a highly armored T-28 aircraft to provide these measurements. The T-28 has reached the end of useful life and must be replaced. The research community has evaluated a number of alternate platforms that can be modified to serve as an SPA. NSF intends the replacement to be a more robust and capable platform that will allow increased on-station time, larger payloads and greater altitude capability.

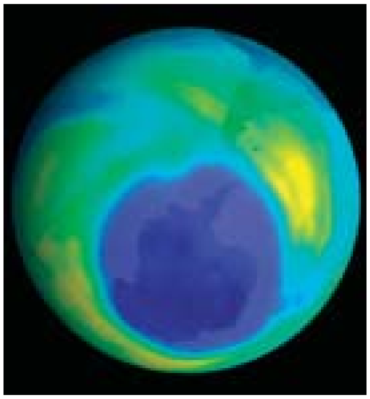
T-28 aircraft.

Upper Atmospheric Observatory Network: With the use of the Internet, it is now possible to form a complex network of upper atmospheric sensors (radars), imagers, lidars, magnetometers and solar observatories to provide continual and nearly global coverage of the Earth's upper atmosphere and ionosphere, both to further our understanding and for practical space weather purposes. These new sensors will all be autonomous and remotely accessible.

Fault Observatory at Depth II: Following the SAFOD penetration and observatory installation within a major strike-slip fault at the seismogenic depth of 4 km, a second penetration and observatory installation will extend the SAFOD results to a different type of faulting and/or deeper depth. Fault conditions including mineralogy, pore fluid pressure, and temperature along with the physics of earthquakes within this different environment will test theories and conditions established in SAFOD. The results will be essential inputs to models of dynamic crustal and mantle motion and earthquake hazard analysis.

Out-years

Frequency Agile Solar Radiotelescope (FASR): The Frequency-Agile Solar Radiotelescope is a multi-frequency imaging array composed of many antennas designed specifically for observing the Sun. It will produce high-quality images of the Sun with high spatial resolution, high spectral resolution, and high time resolution, across more than two decades in frequency. In so doing, it will produce a continuous, three-dimensional record of the solar atmosphere from the chromosphere up into the mid-corona. These qualities represent a quantum leap beyond existing solar radio instruments, yet are well within reach of emerging technologies



GNSS (Global Navigation Satellite System) Earth Observing System (GEOS): GEOS is a constellation of 12 small research satellites for global monitoring of atmospheric water vapor, temperature, atmospheric ozone, ocean altimetry, Earth gravity and space weather parameters. The fleet of instrumented spacecraft envisioned for GEOS will explore the global atmosphere from the surface of the Earth to an altitude of several hundred kilometers, and provide unique geoscience measurements to study the oceans, troposphere, stratosphere and ionosphere as an integrated, interacting system.

Antarctic ozone hole, NASA.

Community Facility for Global Volcanism Research (CFGVR): CFGVR will bring an array of technologies to bear on long-standing problems in volcanic research and provide for the common needs of volcanic researchers.

- Volcano Measurements Facility (VMF): VMF will develop and provide a pool of geophysical, geodetic and atmospheric instruments, and associated wireless communications and remote sensing for the comprehensive and integrated research on volcanic phenomena.
- Volcano Data Analysis System (VDAS): VDAS will make available the vast amounts of existing and anticipated volcano-related data and provide community modeling, computational and analytical tools to the research community. A special focus of VDAS will be the virtual coordination of access to community experimental, computational, and geochemical facilities.
- Volcano Observatory and Monitoring System (VOMS): VOMS will develop a network of observational systems that will allow near-real time monitoring of volcanic activity and hazards. VOMS will also establish deep volcanic observing systems requiring state-of-the-art drilling technologies and high temperature instrumentation.

Eruption of Mt. Lascar in Chile in 1993, Caspar Ammann (NCAR).

Rapid Scanning Ground-Based Radar: A rapid-scanning ground based radar could scan the entire volume of a storm much more quickly than present radar. In the tens of minutes currently required to scan a system, meteorologists have to assume that the storm remains stationary for the entire volume scan or they have to artificially remove the average speed from a storm or estimate advection during the volume scan.

Next Generation Airborne Radar System: ELDORA has been integrated into a Naval Research Laboratory (NRL) P-3 aircraft. The NSF Electra aircraft was removed from service in 2001. Development of a surveillance radar capability displaying real-time radar data in the horizontal is a pressing need. A conformal phased array antenna would be used for airborne weather surveillance radar to allow high-resolution measurements without a need to undertake substantial expensive airframe modifications. The conformal radar would have a much finer beam diameter (yielding greater spatial resolution) since the antenna could be made very large without affecting aircraft drag and performance.

NRL P-3 being outfitted with ELDORA radar at NCAR.

The Challenges Ahead

The future will undoubtedly see substantial change in the way the geoscience community collects samples, performs field and laboratory experiments, exchanges information and data. Information will become more widely and effectively disseminated for use by scientists and educators alike. Disciplinary barriers will be further eroded, data access will continue to revolutionize the way investigators work together, and increasingly researchers will study dynamic earth processes remotely in near real-time. GEO must be prepared to manage a rapid evolution in the observational and computational capabilities that will empower the scientific community to achieve the exciting advances in understanding and prediction of important phenomena in the geosciences.

Selected Atmospheric Instrumentation Websites:

Upper Atmosphere Facilities:

Arecibo Observatory: http://www.naic.edu/
Jicamarca Radio Observatory: http://jicamarca.ece.cornell.edu/
Millstone Hill Observatory: http://hyperion.haystack.edu/
Sondrestrom Facility: http://isr.sri.com/

Lower Atmosphere Facilities:

http://www.geo.nsf.gov//atm/ulafos/laof/start.htm
http://www.ucar.edu/ucar/fac-data.html

Selected Earth Science Instrumentation Website

http://www.geo.nsf.gov/ear/if/facil.htm

Selected Oceanographic Instrumentation Websites

For Ships: http://www.unols.org/

For Ocean Observatories: See DEOS (Dynamics of Earth and Ocean Systems) on http://www.coreocean.org/

For Ocean Drilling: http://www.oceandrilling.org/