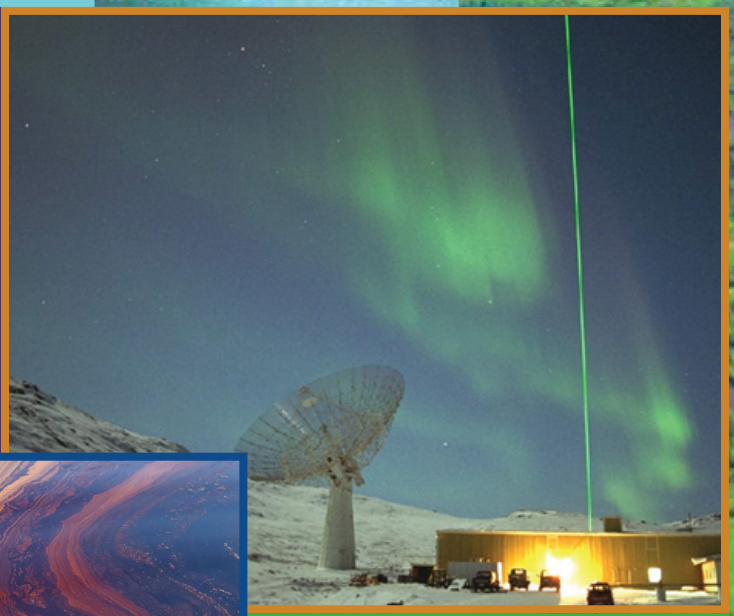
Strategic Frameworks for Education & Diversity, Facilities, International Activities, and Data & Informatics in the Geosciences



A Special GEO Vision Follow-on Report

Foreword

In 2009, the National Science Foundation (NSF) Advisory Committee for Geosciences (AC GEO) released the GEO Vision report, with a call to action for the geosciences community and a series of recommendations to advance the state of geosciences. GEO Vision outlined five grand challenges for the geosciences that continue to be major drivers for NSF's Directorate for Geosciences (GEO) science agenda. These research challenge areas are:

- The Dynamic Earth
- The Changing Climate
- Earth and Life
- Geosphere-Biosphere Connection
- Water: Changing Perspectives

AC GEO members soon realized that an examination of the underlying and cross-cutting foundational areas for the geosciences was necessary in meeting the research challenge areas and the related recommendations. The AC GEO formed subcommittees in order to strategize and more carefully examine the underlying themes that cut across and support the geosciences. The four subcommittees formed – data and informatics, facilities, education and diversity, and international – each created a working group with a charge to develop strategic plans in furtherance of the goals and recommendations set out in GEO Vision.

The results of the subcommittee and workgroup efforts to date have been an enriched dialogue and enhanced collaboration on the foundational themes and activities that support the geosciences across the disciplines. After many months of meeting, planning, and writing, the four workgroups created complementary plans for reaching their goals. We are pleased to share the strategic plans outlined and described in this document and look forward to working with GEO to implement the activities described. We encourage you to review the plans individually and collectively in order to understand the challenges, opportunities, and intricacies of modern geosciences research and education as a whole.

As science and society continue to evolve, the geosciences need to advance along with them and provide leadership and information for sound decision-making. We believe the strategic plans contained within this document are a step in the direction of a sustainable future.

Louise Kellogg
Chair, NSF Advisory Committee for Geosciences
April 2012

Executive Summary

In October 2009, the National Science Foundation's Advisory Committee for the Geosciences (AC GEO) published the GEO Vision Report, which outlines a vision, goals, challenges, recommendations and a call to action for the geosciences community at large. As stated in the report the Geo Vision is to: foster a sustainable future through a better understanding of our complex and changing planet.

The GEO Vision report outlines five grand challenges for the geosciences: 1) the Dynamic Earth; 2) the Changing Climate; 3) Earth and Life; 4) Geosphere-Biosphere Connection; 5) Water: Changing Perspectives. These five challenges, which incorporate both natural and anthropogenic topics, are strong drivers of GEO's current science agenda.

In order to meet the GEO Vision grand challenges AC GEO recognized that support for science and basic research must be coupled with foundational and supporting activities that transcend the geosciences disciplines. AC GEO recognized that as the geosciences cross disciplinary and political boundaries so do its structural and philosophical support systems.

Therefore, AC GEO created four topical subcommittees to focus on data and informatics, facilities, international, and education and diversity. The Directorate for Geosciences established workgroups to support each subcommittee and to develop guidance for the Directorate and its staff in working in the four areas. The primary functions of the workgroups are to:

- *Strategize*: Discuss, provide input, and assist with development of a strategic plan or framework. Identify new opportunities where activities and leadership are needed as well as current activities that align with the strategic objectives.
- *Coordinate*: Identify ways to improve coordination between divisions within the Geosciences, with other directorates within the NSF, with other agencies, and with international research programs and organizations. Coordinate with AC GEO and its subcommittees in their strategic advisory role.
- *Communicate*: Assist with communicating the value and vision of workgroup-related activities in the Geosciences to the Divisions and to other parts of NSF.
- *Advise*: Assist the Directorate with setting priorities related to workgroup activities and serve as a "go to" group for related activities under consideration within the Directorate.

Rapid advances in our understanding of Earth's complex, inter-connected systems have led us to recognize that the well-being of human society is tightly connected to the behavior and evolution of Earth Systems. Increasingly, human activities play an influential role in the behavior of these systems, particularly those related to climate, environmental quality, and natural resources. Significant challenges will confront a growing population in the coming decades as the impacts of global climate change, sea level rise, ocean acidification, diminished fresh water and other natural resources, and natural hazards are realized. Thus, the scientific questions being explored by geoscientists address issues that are among the most important facing the nation.

- *Gather information*: Develop comprehensive knowledge of GEO activities. Reach beyond GEO to gather information about how similar activities are managed in other parts of NSF. Gather information on alternate sources of funding for activities.
- *Define best practices*: Collect information about the most useful frameworks for collaboration and activities. Suggest best practices for including related activities as part of an award.

Part of NSF's mission statement – to promote the progress of science – describes NSF's overall role in advancing research and education in science and engineering across all fields and disciplines and at all educational levels. NSF leadership identified three strategic goals to promote the progress of science for years 2011-2016:

1. Transform the frontiers – seamless integration of research and education as well as close coupling of research infrastructure and discovery.
2. Innovate for society – linkage between NSF programs and societal needs, and the role that new knowledge and creativity play in economic prosperity and society's general welfare.
3. Perform as a model organization – importance of attaining excellence and inclusion in all operational aspects.

The following chapters describe the strategic frameworks developed by each working group. The plans were drafted after months, and in some cases, years, of effort, with careful consideration and input from the research community. The efforts detailed therein complement and reinforce each other, and will enrich and provide multiple modes of support for fundamental geosciences research. The strategic plans are intended as pathways to address the recommendations in GEO Vision and to advance the state of geosciences as a whole. In addition, the strategic plans complement and support strategic plans under development by the GEO Divisions. The four plans aid the GEO Directorate in meeting the goals of the NSF strategic plan, as revised for 2011-2016: transforming the frontiers, innovating for society, and performing as a model organization (see sidebar).

This Executive Summary provides a brief description of each topic area with its main goals articulated as well as a table that crosswalks the respective goals of the four thematic areas to the recommendations in the GEO Vision report. The chapters that follow provide greater details on the four thematic areas.

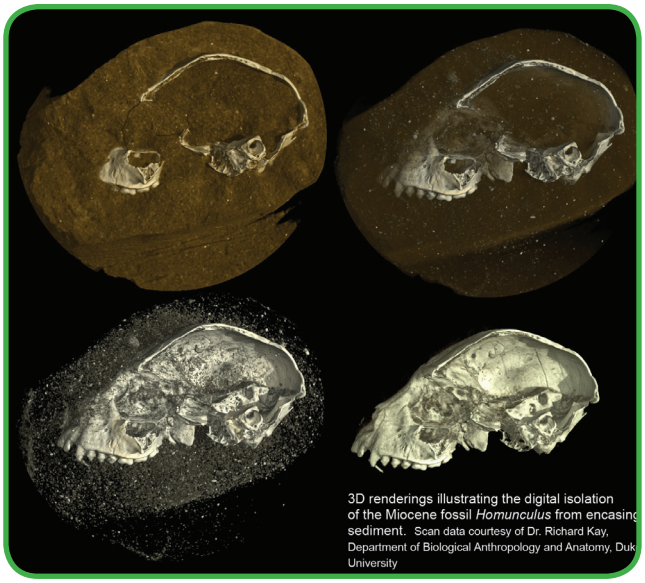
Education and Diversity

GEO seeks to establish a cohesive, high-impact portfolio of geosciences education and outreach investments that: addresses geosciences community needs; complements investments being made by other NSF Directorates and other Federal agencies; supports the goals of the NSF Strategic Plan and the GEO Vision framework, and; promotes integration of research and education. Broadening participation *of scientists and students from traditionally underrepresented* groups will be a priority in all aspects of GEO's business operations, from grant funding to merit review to staff hires. The strategic framework for Education and Diversity contained in this document provides an overview of GEO's Education and Diversity (GEO E&D) program priorities for the next five years. The two over-arching goals established for GEO E&D via an intensive and inclusive strategic planning process are:

- Advancing Public Literacy in Earth System Science – *A scientifically literate public that understands the interconnected and inter-dependent non-living and living systems of Earth, uses that knowledge for informed decision-making, and advances its understanding of Earth Systems through life-long learning in formal and informal educational settings.*

- Preparing the Geosciences Workforce of the Future – *A future geosciences workforce, reflecting the nation's diversity, that is skilled in science, technology, and other relevant disciplines necessary to advance GEO-funded research and overcome critical scientific and societal challenges in the geosciences.*

In addition, GEO is involved in NSF's cross-directorate, interdisciplinary effort called Expeditions in Education (E^2) to complement and advance progress towards its education and diversity goals. E^2 will infuse cutting-edge science and engineering into the preparation of a world-class scientific workforce for the twenty-first century, and ensure that all NSF education and workforce investments are drawing on the latest educational theory, research, and evidence. The initiative will use new ideas from the best and most exciting of NSF-supported scientific advances and knowlege.



3D renderings illustrating the digital isolation of the Miocene fossil *Homunculus* from encasing sediment. Scan data courtesy of Dr. Richard Kay, Department of Biological Anthropology and Anatomy, Duke University

Facilities

Facilities are inextricably linked to geosciences. They are central to furthering our understanding of the earth system. The Directorate for Geosciences has convened a Facility Team to look at all of the facility activities undertaken within the Directorate including Major Research Equipment and Facilities Construction (MREFC)-class, mid-size infrastructure, and Major Research Instrumentation (MRI) and grant-funded facilities, sensors and instrumentation.

Many research projects in the Geosciences require shared community facilities to support the study of complex, interdependent processes. To meet these challenges with foresight there must be a visionary facility plan that matches the GEO Vision. GEO Vision points to the need to take an interdisciplinary

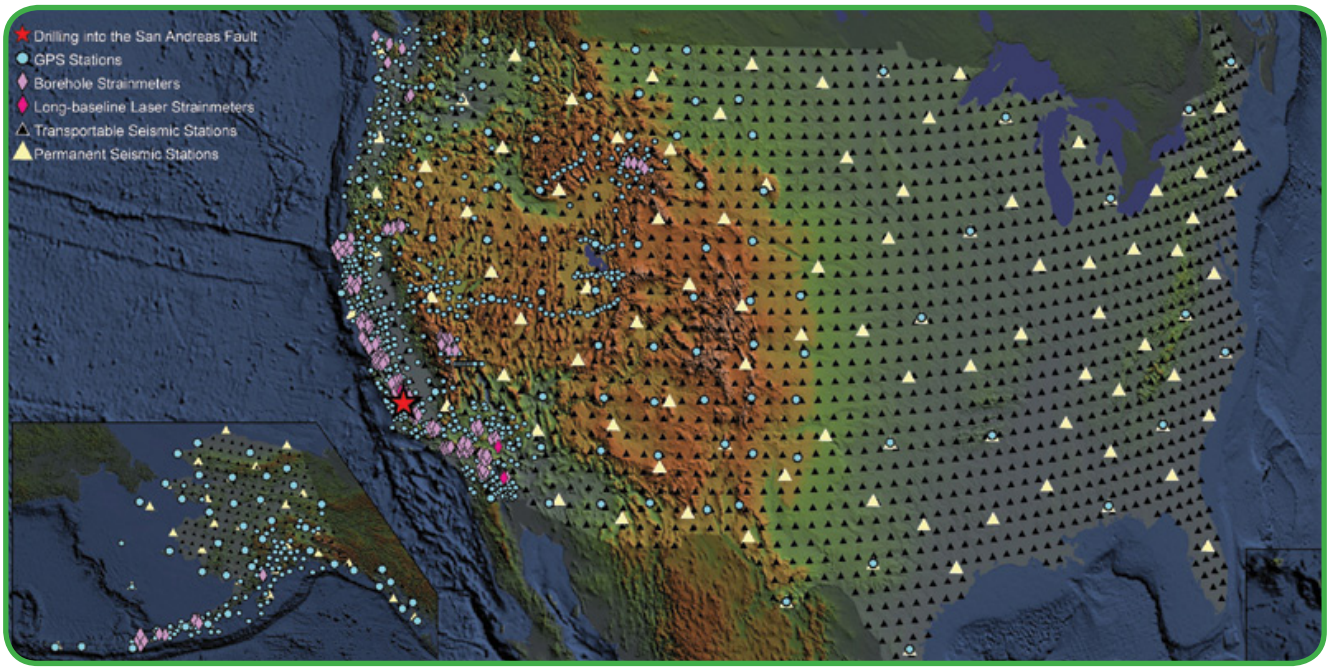


Figure 1: Rendering of Earthscope - Plate Boundary Observatories and Stations. Credit: UNAVCO.

approach for meeting the challenges facing a sustainable future. Geosciences facilities must provide capabilities for and stimulate the integration of research across the boundaries of relevant scientific disciplines. Thus, GEO will advance support for observational, sampling, analytical and experimental laboratory and computational multi-user facilities that will allow the geosciences workforce to:

- Maintain facility capabilities to address frontier science questions, realize interdisciplinary research collaboration and educate the next generation of scientists and inform the public.
- Disseminate rapidly integrated data products to inform timely decisions necessary to foster a sustainable Earth system.
- Enable fundamental new discoveries of linkages between components of the Earth System over a wide spectrum of the time and space continuum.

Data and Informatics

Geoscientists are increasingly engaged in data intensive science and investigation, data management, and long-term storage and access issues including the full data life cycle. New types of measurements are being made or are planned to measure the Earth system across the spatiotemporal scales required to comprehend its full complexity from the core to its crust, the depths of the ocean and subsea floor all the way to the edges of space. Many new systems for monitoring or modeling earth systems have come on-line, each producing copious amounts and types of data. Given the need to navigate the vast sea of data, the Data and Informatics subcommittee has set the following goals for the role of data in geosciences endeavors:

- Data-enabled science is realized, with the hardware, software, and human capital infrastructure to increase the interoperability and interworkability of geosciences (and other domain) data sets.
- Develop new computational infrastructure that is widely available, with new and enhanced computational platforms, tools, and data centers that allow integration of Earth subsystem models into a whole Earth model.
- Improve connections to facilities to study the whole Earth System. Foremost for geosciences is the need to facilitate transparent data transfer from the field into data systems and applications.
- Research networks are created to enhance multidisciplinary research through shared data, modeling, and education.

NSF is facilitating a community dialog with a goal of transorming the conduct of research in geosciences by supporting the development of a community-guided CI, an EarthCube, to integrate data and information for knowledge management across the geosciences. The purpose of the project is to significantly increase the productivity and capability of researchers and educators by integrating all geosciences data, information, knowledge and practices in an open, transparent and inclusive manner.

"Deeply aware that geosciences research transcends national boundaries, GEO supports numerous international cooperative arrangements to enable researchers to develop scientific and financial capabilities needed to conduct research to understand more fully the origins of the Earth as well as its climate and environment. These arrangements include global programs in areas such as climate, seismology, meteorology, paleontology, geosphere-biosphere interactions, marine ecosystems, and ocean drilling. GEO is also involved with regional and bilateral arrangements with scientists, engineers, and institutions from numerous countries across all continents. Such arrangements vary from countries with scientific capabilities akin to our own to those with emerging economies facing specialized geographic issues." GEO Vision report (AC-GEO, October 2009)

International

International relationships and activities are central to furthering our understanding of the Earth system. Increasingly, centers of research excellence are emerging across the globe and new ideas and research are resulting from intellectual interactions of people with diverse backgrounds. Consequently, U.S. scientists and engineers must be globally engaged and able to operate effectively in teams/networks with partners from different nations and cultural backgrounds. International partnerships are, and will be, increasingly indispensable in addressing critical geosciences issues.

Due to the centrality and importance of international collaboration to the advancement of the geosciences and attainment of a sustainable human future, the AC GEO subcommittee and supporting workgroup are developing a strategic framework for international activities that optimizes investments to facilitate discovery and innovation with significant societal impact. The subcommittee has articulated the following goals for the GEO international program in support of the GEO Vision recommendations:

- Catalyze research excellence via international partnership and collaboration
- Leverage existing and future international scientific capabilities and intellectual resources to strengthen U.S. capacity for international engagement
- Provide mechanisms to obtain new "global" data sets and access to critical research sites

The GEO Directorate is driven by the mission and vision of the geosciences community as a whole, as articulated by the AC-GEO in the GEO Vision report. Fulfilling the missions of GEO, its Divisions, and the geosciences community as a whole, would not be possible without significant dedication to, and examination of, the critical, cross-cutting, thematic areas of facilities, education and diversity, international collaboration, and data and informatics. As the geosciences cross disciplinary and political boundaries, so do its structural and philosophical support systems.

Advancement in the four thematic areas of data and informatics, facilities, international, and education and diversity is essential to the advancement of the geosciences in an increasingly complex, data-rich, transdisciplinary and international landscape. Work in these cross-cutting areas will increase collaboration and partnership, bring data to decision-makers and the public, enhance public involvement and science literacy, and provide leadership and direction for geosciences research and education. The role of each of these areas in meeting the recommendations set out by AC GEO in GEO Vision is illustrated in Table 1.

Table 1

GEO Vision Recommendations	Education Goals		Data and Informatics Goals				Facilities Goals			International Goals		
	Advancing public literacy in earth system science	Preparing the geosciences workforce of the future	Data-enabled science is realized...	New computational infrastructure is widely available with new tools...	Improve connections to facilities to study whole Earth system...	Research networks created to enhance multidisciolinary research	Enable fundamental new discoveries of linkages in Earth system	Disseminate rapidly integrated data products to inform timely decisions...	Capability to address frontier science, interdisciplinary collaboration, education, inform public	Catalyze research excellence through collaboration	Leverage scientific and intellectual resources to strengthen U.S, capacity...	Mechanisms to obtain global data sets and access to critical research sites
Sustain and nurture fundamental geosciences disciplines	✓	✓					✓		✓	✓	✓	
Reach out in bold new directions, engage other disciplines	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
Embrace a culture that recognizes that transformational research involves an element of risk				✓			✓	✓		✓	✓	✓
Invest wisely in and responsibly manage the next generation of tools, technologies, and techniques, including advanced-computation to enable cutting-edge research			✓	✓	✓	✓	✓	✓			✓	✓
Communicate the critical role that geosciences plays in reducing risks from natural hazards	✓		✓	✓		✓		✓	✓	✓	✓	✓
Build effective and enduring partnerships within NSF, other federal agencies, private sector, and international organizations	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓
Recognize explicit need for geosciences to adopt challenge of increasing resiliency of natural systems	✓				✓	✓	✓		✓		✓	✓
Build bridges between geoscience researchers and K-12 to promote understanding of geosciences	✓	✓	✓		✓	✓		✓		✓	✓	
Create broad and diverse cadre of geosciences researchers who can use creative approaches to education and literacy at all levels	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	
Convey central geosciences research, findings to policymakers, thought leaders in building a sustainable future	✓		✓		✓	✓		✓			✓	✓

Credit: Chu Research Group, Chinese Academy of Sciences

Credit: David Valentine

GEOSCIENCES EDUCATION AND DIVERSITY STRATEGIC PLAN 2011-2016

The mission for NSF's Directorate for the Geosciences (GEO) is to support research in the atmospheric, earth, and ocean sciences. Along with the mission to support research also comes the responsibility to address the nation's need to understand, predict and respond to environmental events and changes in order to use the Earth's resources wisely.

Introduction

Our future sustainability and prosperity require a new interdisciplinary geosciences workforce that reflects the nation's diversity and has the capacity to work collaboratively to develop innovative solutions to meet the challenges that lie ahead. In addition, all citizens need to understand the science of Earth processes well enough to make evidence-based decisions in their personal lives and communities, in response to continued evolution of coupled human and natural Earth Systems. To achieve these twin goals – an Earth System Science literate public and a diverse, geosciences workforce of the future – we need effective, scientifically accurate, and widely adopted geosciences education programs that serve all learners, of all ages, and from all walks of life.

Mission and Vision for a Unified GEO Education and Diversity Portfolio

GEO seeks to establish a cohesive, high-impact portfolio of geosciences education and outreach investments that: addresses geosciences community needs; complements investments being made by other NSF Directorates and other Federal agencies; supports the goals of the NSF Strategic Plan and the GEO Vision framework; and, promotes integration of research and education. Broadening participation of scientists and students from traditionally underrepresented groups will be a priority in all aspects of GEO's business operations, from grant funding to merit review to staff hires.

The GEO E&D portfolio has evolved to lie along a continuum between pure geosciences education research that is aligned with investments being made within the Education and Human Resources (EHR) Directorate and pure geosciences research that affords opportunities for student and educator research and training. GEO is playing a strong role in NSF's cross-directorate effort called Expeditions in Education. E^2 brings the educational and research missions of NSF together to consolidate, leverage, and focus efforts to "move the dial" towards achieving important national goals in STEM education and human capital development. E^2 encompasses all of the science and engineering fiels that NSF funds to develop approaches to engaging all citizens iin STEM in both formal and informal settings. GEO has a long history of investment in education and workforce development activities. Going forward, NSF, and GEO in particular, seeks to continue its leadership role, in partnership with sister agencies such as NOAA, NASA, DOE, and USGS to achieve this vision for geosciences education and workforce development.

Goals and Strategic Approaches

The current GEO Education and Diversity portfolio is designed around two goals.

GOAL 1: ADVANCING PUBLIC LITERACY IN EARTH SYSTEM SCIENCE. A scientifically literate public that understands the interconnected and inter-dependent non-living and living systems of Earth, uses that knowledge for informed decision-making, and advances its understanding of Earth Systems through life-long learning in formal and informal educational settings.

GOAL 2: PREPARING THE GEOSCIENCE WORKFORCE OF THE FUTURE. A future geosciences workforce, reflecting the nation's diversity, that is skilled in science, technology, and other relevant disciplines necessary to advance GEO-funded research and overcome critical scientific and societal challenges in the geosciences.

The portfolio framework was developed in accordance with the following guiding principles:

- Soliciting input from geosciences research and education communities when defining priorities;
- Taking a leadership role within NSF to promote dialogue and coordination regarding Earth System Science literacy and geosciences workforce investments;
- Developing resources and tools for the GEO Principal Investigator community that can facilitate meaningful and cohesive broader impacts activities for education and diversity;
- Fostering interagency partnerships that promote a coordinated Federal investment in Earth System Science education and geosciences workforce development;
- Pursuing collaborations with EHR to make strategic investments that advance geosciences education research, reform of geosciences education within the broader context of STEM education reform, and capacity building at minority-serving institutions.

The following section describes the goals, objectives and implementation strategies for GEO's Education and Diversity portfolio. Via a multi-year, multi-stakeholder process GEO's Education and Diversity Working Group drafted a comprehensive strategic plan from which the following section is derived.

Implementation Strategies:

- Promote use of Earth System Science education as a tool for strengthening STEM education and public science literacy
- Support E&D projects/programs that build on best practices from research on learning, incorporate current scientific knowledge, and leverage GEO investments
- Support efforts to disseminate best practices through annual meetings of the geosciences education community.
- Support development of an integrated Earth System Science Literacy framework and associated learning resources
- Foster connections between STEM education and traditional sciences that enhance geosciences education
- Strengthen pre-service teacher training and in-service teacher professional development on key literacy concepts
- Require incorporation of the Earth System Science Literacy frameworks in all GEO E&D program solicitations and GEO-funded broader impacts activities.

GOAL 1: ADVANCING PUBLIC LITERACY IN EARTH SYSTEM SCIENCE

Objective 1.1: Building a Community of Practice.

GEO's E&D programs support a continuum of efforts that range from STEM education research, supported primarily through the EHR Directorate, to

programs that address unique issues within geosciences education, to education and outreach activities that are intimately linked to, and leverage, GEO-funded research. GEO tries to focus on making catalytic investments or incubating new and effective concepts that can be scaled up, disseminated, or sustained. In addition, GEO explores ways that geosciences education can help to advance STEM education and public science literacy more broadly.

Objective 1.2: Supporting Educators.

Geosciences education and research communities have developed frameworks that depict the 'big ideas', or essential principles and concepts, that all citizens should understand to be literate in Earth System Science. These frameworks for Ocean Literacy, Atmospheric Science Literacy, Climate Literacy, and Earth Science Literacy provide important foundations for development of educational resources that can be used in a variety of learning environments. GEO's E&D programs support development of instructional resources, educator training and professional development programs that advance understanding and use of the 'big ideas."

Objective 1.3: Using Geosciences Data for Education.

With the increasing societal relevance of environmental geosciences topics, opportunities to use geosciences data to engage students and citizens in geosciences research are increasing. Successful programs like Global Learning and Observations to Benefit the Environment (GLOBE) demonstrate that students learn science better when involved with collection and manipulation of data and that non-scientists can contribute meaningfully to the scientific enterprise.

Objective 1.4: Supporting Informal Learners.

GEO aims to support development of pedagogically appropriate educational resources that can be accessed through a variety of informal learning mechanisms and help educators in informal learning environments be more knowledgeable and effective in delivering this content. Technology has broken down the barriers between education in formal classrooms and informal learning environments, including museums, science centers, and home. These changes raise significant challenges regarding quality control, authenticity, and scientific accuracy. New tools that use emerging technologies that facilitate engagement of the public in GEO-supported research should be developed, tested, and disseminated. New geosciences research programs which will offer real-time data generation and access, open the door to engaging an army of 'citizen scientists'. New models for professional development of decision-makers that helps them to understand geosciences concepts in ways that are relevant to their decisions should be created, tested, and deployed.

Implementation Strategies:

- Strengthen experiential programs that provide authentic, hands-on geosciences research experiences that promote the Earth System Science literacy concepts
- Expand Research Experiences for Undergraduates (REU) programs to reach a wider population of undergraduate students, including those at community colleges
- Leverage research investments in large facilities, Major Research Equipment and Facilities Center programs, and GEO-related Science and Technology Centers for student and educator research and education purposes.
- In collaboration with EHR and SBE, develop new programs and resources that help policymakers and decision-makers understand the science of climate change and its impacts.

Objective 1.5: Engaging Scientists in Education.

In fulfilling NSF's mission "to promote the progress of science; to advance the national health, prosperity, and welfare; to secure the national defense…," there is an expectation that the scientific community will be engaged in making research results publically available. GEO will continue to support programs that help scientists become more effective communicators of their science; facilitate collaborative partnerships between geoscientists and educators who have complementary expertise; and, develop web-based tools that enable GEO investigators to identify and leverage relevant educational programs that are supported elsewhere.

Implementation Strategies:

- Support scientists' professional development to strengthen their impact in education and outreach
- Partner with EHR to develop and test appropriate learning resources and tools that educate students about Earth System Science concepts and help disseminate best practices.
- Support efforts to expand advanced high school Earth System Science courses, including dual-credit, AP and Honors
- Partner with other agencies and stakeholders to articulate common goals, standards, and metrics and improve the quality of, and access to, Earth System Science content in the K-16 setting.

Objective 1.6: Reforming STEM Education Policies.

There is a natural role for the geosciences to play in advancing broad STEM literacy and engaging students in STEM careers. Earth Science is intrinsically fascinating for students and of clear relevance to their daily lives. Earth Science concepts are often among the first science concepts to which students are exposed, and thus can influence student attitudes towards science and science careers in general. There are many barriers to widespread availability of high quality geosciences education. GEO should work with EHR to promote activities that improve quality and availability of geosciences education in formal learning settings.

GOAL 2: PREPARING A TALENTED AND DIVERSE GEOSCIENCE WORKFORCE FOR THE FUTURE

Implementation Strategies:

- Increase student engagement in geosciences and awareness of career opportunities, particularly among minority communities
- Educate guidance counselors about geosciences career opportunities
- Engage in public marketing about geosciences importance and relevance
- Issue a Dear Colleague Letter emphasizing importance of, and strategies for, broadening participation in higher education
- Foster opportunities for collaborations between industry and academia to identify workforce needs and share best practices for broadening participation.

Objective 2.1: Building and Sustaining the Pipeline.

Innovation in science and technology has long been America's economic engine. Yet, despite many healthy employment opportunities in STEM-related occupations, today's students are not choosing to pursue advanced degrees or careers in STEM fields at the level needed. To address this situation, GEO should support aggressive outreach and marketing efforts to parents, educators, and guidance counselors; promote and facilitate linkages to careers in geosciences; and, increase student exposure to high-quality education and research experiences in geosciences – especially at the critical juncture between high school and college, and within minority-serving institutions.

Objective 2.2: Keeping Geosciences Education Programs Healthy.

Requirements for undergraduate- and graduate-level geosciences education are evolving rapidly, as issues such as climate change impacts and sustainability move to the forefront. Traditional geosciences departments are finding they must adapt curricula and research opportunities to remain competitive and serve the increasingly interdisciplinary field of Earth System Science, as well as provide students with skills to pursue careers at the boundaries between science and society. GEO should invest in programs that: increase viability and utility of geosciences departments and programs by investigating effective educational models, pedagogy, and resources that are based on current education research; seeking and addressing input from employers regarding needed skills and abilities; and, capitalizing on emerging technologies that facilitate learning.

Implementation Strategies:

- Develop better approaches for monitoring progress related to broadening participation and expand the measure of success to include MS, BS, and AA degrees
- Leverage EHR investments in programs to broaden participation in STEM education and career pathways
- Develop tools to increase student awareness of scholarship, internship, and mentoring opportunities to support their education and advancement
- Articulate a plan for improving access to geosciences for persons with disabilities, with relevant stakeholder input
- Encourage professional society efforts to provide training for scientists as mentors
- Foster development of cyberinfrastructure that facilitates integration of research and education
- Foster integrative, interdisciplinary research with other directorates

Earth System Science requires development of a new generation of interdisciplinary, integrative scientists capable of working as part of a team to address questions at the interface of science and society. They must also be able to communicate effectively with the general public and policy makers to build a more scientifically literate and sustainable society.

Objective 2.3: Preparing Students for Geosciences Careers.

In contrast to most other STEM fields, there are many educational pathways into the geosciences, particularly at the graduate student level. For example, it is not uncommon for PhD geosciences students to enter graduate programs with Bachelor's degrees in a core science or math discipline. GEO will continue to support programs that promote exposure to the geosciences, retention of students at the undergraduate level, and completion of advanced degrees in the geosciences leading to a variety of careers in academia, government, and the private sector.

Objective 2.4: Engaging Scientists in Workforce Development.

GEO's greatest asset is the cutting-edge research, and the scientists and technical personnel who conduct this work, being supported through GEO's investments. The scientific community holds an important responsibility for cultivating the next generation of geoscientists that directly builds on its research infrastructure. Providing students with authentic experiences in geosciences research as undergraduates, whether through summer REU site programs, summer field camps, one-on-one research experiences with a faculty mentor or innovative hands-on courses, is central to developing our future workforce.

Implementation Strategies:

- Build Earth System Science capacity at minority-serving institutions, including community colleges, both internally and through partnerships with universities and research centers
- Foster articulation between 2-year and 4-year institution programs that provide geosciences training
- Establish regional or disciplinary alliances in Earth System Science that engage large and small institutions
- Support and expand effective programs that provide mentoring, networking, and leadership development – particularly for women professionals and minority scientists and students
- Promote and expand activities focused on success and retention of women in the academic and non-profit sectors
- Establish policies for GEO-investigators that minimize the negative career impacts associated with parental or family leave obligations

Objective 2.5: Building Capacity at Minority-Serving Institutions (MSIs).

Many undergraduate students begin their education at a community college. More than 50% of students at community colleges are from underrepresented backgrounds, but only 14% of these colleges offer geosciences associate degrees. It is not necessary for every MSI or community college to have a geosciences program, but partnerships between geosciences degree granting institutions and MSI and community colleges should be fostered to make the discipline more visible and viable to students from the MSIs and community colleges. These collaborations should also facilitate faculty and student engagement in research and other career opportunities.

Objective 2.6: Retention through Mentoring and Networking.

A variety of strategies can be employed to engage students in learning about geosciences and recruiting them to pursue degrees and careers as geoscientists, but the challenge continues to be retaining them at critical decision points and preparing them for successful workforce entry. GEO should continue to support such efforts and explore additional models for creating interdisciplinary, collaborative networks and mentoring resources that help to keep the scientific community's vitality through infusion of younger and diverse talent prepared to explore new research frontiers.

Challenges

Innovation in science and technology has long been America's economic engine. Yet, despite many healthy employment opportunities in STEM-related occupations, today's students are not choosing to pursue advanced degrees or careers in STEM fields at the level needed, and recruitment of traditionally underrepresented students – a growing segment of the population – has been particularly slow for STEM fields. This lack of engagement between under-represented groups and the geosciences creates barriers to educating the broad public about fundamental Earth System Science concepts, engaging the best and brightest minds from all sectors of our society in the pursuit of related degrees and career paths, and recruiting effective educators with relevant scientific background. These obstacles are not uniquely NSF's to solve; instead, success will require a strategic and coordinated inter-agency effort to foster necessary reforms. Going forward, GEO seeks to continue its leadership role, in partnership with sister agencies such as NOAA, NASA, DOE, and USGS.

Conclusion

NSF is poised to lead a broad collaborative effort to achieve this vision for geosciences education and workforce development. The exciting research agenda outlined in the Directorate for Geosciences GEO Vision Report focuses on many societally relevant topics and capitalizes on new technical capabilities that greatly enhance our ability to observe, model, and predict Earth System phenomena. This research agenda offers unprecedented opportunities to engage the scientific community in education and outreach activities, as well as provide authentic research opportunities in the geosciences for students, educators, and citizen scientists. Advances in the learning sciences and new cyber-enabled technologies are paving the way to better instructional approaches that improve our ability to teach learners of all ages – in both formal and informal educational settings – about complex geosciences concepts.

The Nation's capacity for innovation and global competitiveness depends on a workforce well-prepared for the twenty-first century and a citizenry that is science-literate. GEO's Education and Diversity activities and NSF's E^2 investments will leverage two important assets of NSF: research that is transforming the frontiers of science and engineering and leading to innovation for society; and research and development to improve STEM teaching and learning for the twenty-first century. The E^2 vision is to *engage*, *empower*, and *energize* America's populace with STEM and to help create tomorrow's STEM leaders. GEO's and NSF's E^2 investments will ensure that learners have access to current science and opportunities to glimpse the frontiers.

GEOSCIENCES FACILITIES STRATEGIC PLAN 2011-2016

Introduction

Facilities are inextricably linked to geosciences. Facilities include observing platforms, sophisticated laboratory analytical or experimental instrumentation, networks of field instruments, computational capabilities and community models and tools that are widely available to support a broad community of users. They are central to the realization of GEO Vision and the NSF Strategic Plan and to furthering our understanding of the Earth system. Across the geosciences, facility investments range from shared use instruments with annual operating costs of a few hundred thousand dollars to expansive centers of excellence where annual operations exceed one hundred million dollars. All GEO community facility investments are guided by the following common principles:

- Be grounded in and driven by the basic research programs of NSF;
- Perform at the cutting edge of discovery, continuously evolving and improving technology, 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.

Mission and Vision

The mission for NSF's Directorate for the Geosciences is to support research in the atmospheric, Earth, and ocean sciences. This mission cannot be addressed without state-of-the-art facilities and well-conceived, effective and persistent educational and training programs directly linked to facilities.

GEO's research challenges require shared community facilities to support the study of complex, interdependent processes. GEO's support and investment in facilities must be strategic in order to address needs, leverage resources, and train the next-generation geosciences workforce. The vision for GEO Facilities is predicated on a framework which:

- Provides geoscientists critical data on scientifically and strategically important aspects of the Earth system.
- Takes advantage of advances in sensing, telecommunications, computing, and distributed processing technology.
- Provides geoscientists long-term databases necessary to understand the whole Earth system and how it changes through time (e.g., through global networks of interactive, autonomous, and smart low-power sensors).
- Helps geoscientists assimilate, explore, and understand observations obtained from disparate databases through advanced cyberinfrastructure.

This chapter provides an overview of the strategic framework for GEO- supported facilities. GEO's portfolio of investments, coupled with the investment of partners, will be essential to meet the challenges defined in GEO Vision and advance discovery in the most urgent issues identified in GEO Vision.

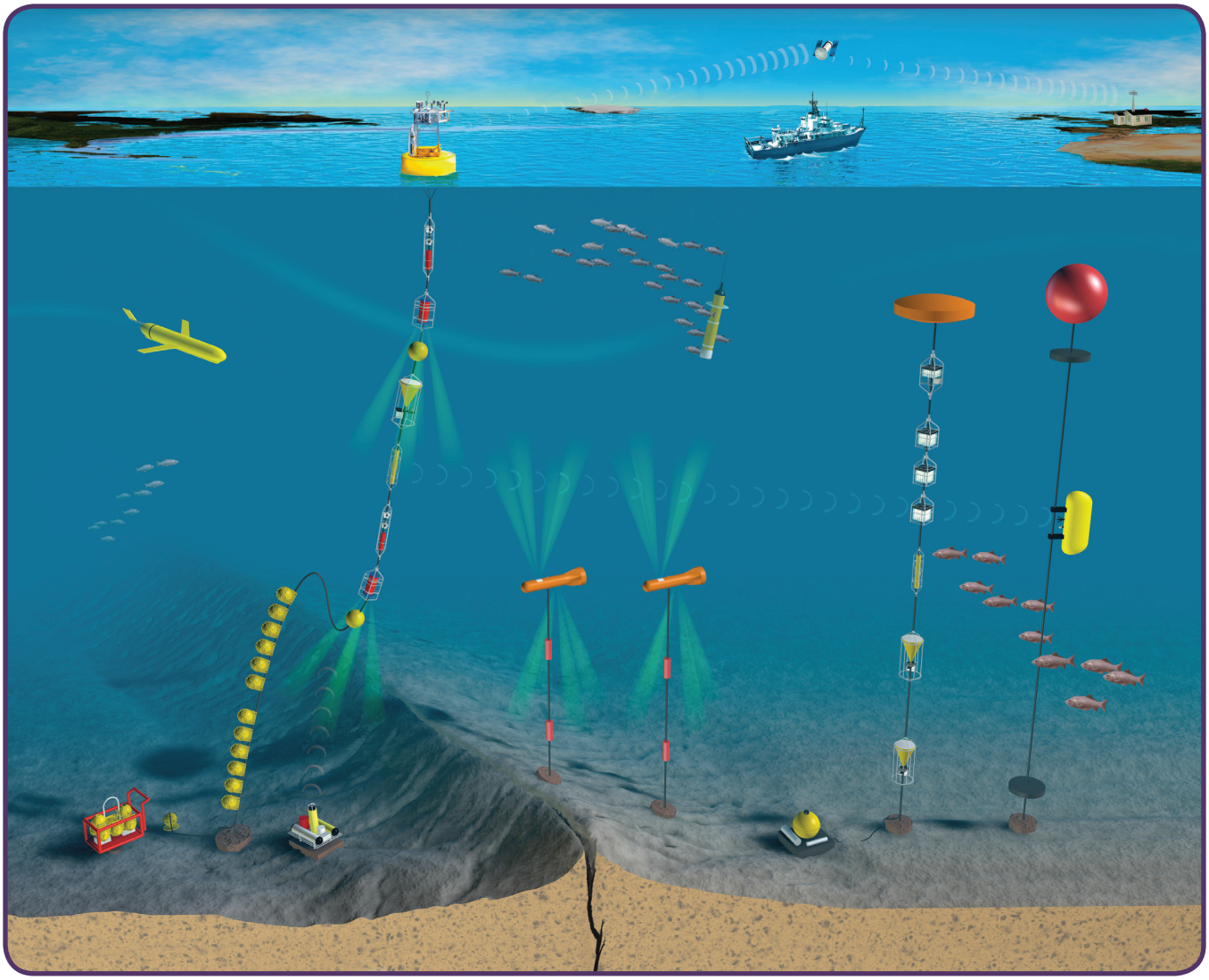


Illustration by E. Paul Oberlander and Jack Cook, Woods Hole Oceanographic Institution.

The GEO facilities working group has articulated a set of goals for a strategic and holistic approach to facilities investments. The following paragraphs provide an overview of the goals for the GEO facilities program for 2011-2016.

Goals

Geosciences facilities are needed to grapple with socially-relevant research and to provide timely data products to inform decisions for a sustainable human future. Over the next five years GEO will advance support for new observational, sampling, analytical and experimental laboratory and computational multi-user facilities that will engender fundamental new discoveries of linkages between components of the Earth System over a wide span of time and space. Such facilities will foster genuine interdisciplinary research collaboration and continued partnerships among organizations and nations to optimize resources, share data, and realize efficiencies. In addition, facility support will be tied to outreach and education efforts to citizens and students at all education levels.

Thus, GEO will advance support for observational, sampling, analytical and experimental laboratory and computational multi-user facilities that will allow the geosciences workforce to:

- Maintain facility capabilities to address frontier science questions, realize interdisciplinary research collaboration, and educate the next generation of scientists and inform the public.
- Disseminate rapidly integrated data products to inform timely decisions necessary to foster a sustainable Earth system.
- Enable fundamental new discoveries of linkages between components of the Earth System over a wide spectrum of the time and space continuum

Goal 1: Maintain facility capabilities to address frontier science questions, realize interdisciplinary research collaboration, and educate the next generation of scientists and inform the public.

Facilities must be refurbished and upgraded to maintain capabilities that are priorities to address frontier science questions. Fiscal realities require optimization of resources that may require changes to the mission, scope and purpose of facilities. Facilities that do not address current priorities or anticipated future priorities may need to be scaled back significantly.

Goal 2: Disseminate rapidly integrated data products to inform timely decisions necessary to foster a sustainable Earth system.

Cutting-edge geosciences facilities will enable fundamental new discoveries of linkages between components of the Earth System providing citizens and decision-makers with timely information necessary to foster a sustainable Earth system.

NEON will be a collaborative research platform of geographically distributed infrastructure connected via the latest information technology. By combining in-situ sensing with remote sensing observations, NEON will address pressing environmental questions on regional to continental scales. Credit: NSF.

Goal 3: Enable fundamental new discoveries of linkages between components of the Earth System over a wide spectrum of the time and space continuum.

The geosciences community must take advantage of advances in sensing, telecommunications, computing, and distributed processing technology to assimilate, explore, and understand observations obtained from disparate databases. Simulating the Earth system with confidence will require observations and concomitant models that span the time-space spectrum from picoseconds to giga-annum and from angstroms to astronomical units. Similarly, observations, theory, and laboratory experiments will greatly improve our understanding of the Earth system and lead to advancement in numerical simulation.

Strategic Approaches

Make Strategic Investments such that GEO-supported facilities allow geoscientists to address the research challenge areas identified in the GEO Vision report.

Frontier geosciences research addressing the real-world challenges described in GEO Vision requires sophisticated and long-term observing, data collecting, and dissemination and analysis systems. The future will be moderated by fiscal reality that dictates that new capabilities realize economies of scale

and utilize energy efficient technologies to allow for sustainable operations both fiscally and through low energy consumption. Advanced facilities must be designed to support multiple issues and disciplines, and be available as community resources. Scheduling and prioritizing access to resources must be transparent in order to ensure the broadest participation of intellectual talents.

"Invest wisely in and responsibly manage the next generation of tools, technologies, and techniques, including advanced computation to enable cutting edge research." Geo Vision report

Requests for facility support are examined via traditional NSF review processes that require considerations of a variety of factors. With emerging research frontiers, new facility capabilities, and novel facility usages, it is essential that NSF Program Officers, expert evaluators, and facility operators engage in structured and transparent dialog to ensure the highest probability of scientific success. In addition, careful attention must be given to the balance between facility and research obligations with a goal of engendering the greatest opportunity for discovery.

Form Partnerships. Seek partnerships at all levels of government, academia, industry and with international collaborators.

GEO supports facilities primarily because of their utility to NSF investigators. However, in many if not most cases, these facilities are community-wide resources that receive support from multiple NSF programs, multiple agencies or other countries. Partnerships are critical in providing geosciences infrastructure. Effective collaborations among NSF directorates at many levels have led to joint funding of numerous scientific activities and concomitant sharing of facilities and cyberinfrastructure. Likewise, numerous collaborations across agencies and nations have provided geoscientists with the tools and information that are essential to advance the frontiers of human understanding. Advances in instrumentation, observing systems and platforms, and modeling have transformed views on the Earth system. GEO has enabled U.S. scientists and engineers to be leaders in developing new ways to observe the Earth system. In partnership with other federal agencies and international partners, GEO has unrivaled capabilities to deploy equipment in the field to observe key processes of the Earth system.

GPS Monument Installatoin, Mt. St. Helens, WA. Credit: M. Jackson, UNAVCO

In the future, collaborations will be more important, and GEO will continue to nurture partnerships to facilitate geosciences research and discovery to the fullest extent possible. Partnering will allow NSF to support global-scale geosciences research in the face of budgetary constraints. To this end, GEO staff and management expend considerable time and energy to engage with other federal agencies and to build interpersonal relationships necessary to foster collaboration and cooperation. GEO participates in a large number of interagency working groups to exchange information and to leverage investments.

Develop the workforce, educate the next generation of geoscientists and the wider community.

The realization of a sustainable Earth system will ultimately depend on future decision makers who must be Earth system science literate. Geosciences facilities play a critical role in educating the next generation of geoscientists through experiential learning and hands-on training. Experiences at facilities stimulate young minds, foster professional workforce retention, and serve the GEO Vision Call to Action for pressing societal needs.

To properly use and understand the output from facilities requires a knowledgeable workforce. In partnership with universities, community colleges, and federal and international partners, GEO supported infrastructure and their management will play a critical role in educating the next generation of geoscientists who will ultimately be responsible for effective use of GEO infrastructure and play a vital role in designing the GEO facilities of the future.

Challenges

GEO investments in facilities must be strategic, such that facility costs do not compromise the core science and education programs. Support to facilities represents a considerable portion of geosciences resources and there are often risks associated with cost, risk and project management, and the need to balance competing priorities. GEO continually weighs the costs of construction, operation, and maintenance of facilities against its benefit to, and/or impact on, the core science and education programs. It is imperative to factor in out-year operation and maintenance (O&M) costs and appropriate adjustments of core science and education programs to ensure the facility is fully utilized by a broad community of researchers and educators.

Conclusion

The continuous stream of geosciences discovery is substantially coupled to the relentless march of technological innovation and engineering advancements. Geosciences researchers, technologists, engineers, computer scientists and educators demonstrate a remarkable ability to build cutting-edge facilities from the ever-increasing foundational building blocks of technology. State-of-the-art facilities will play a vital part in addressing geosciences research challenges. With the portfolio of existing, new, and planned facilities, the geosciences community will be uniquely positioned to provide advice critical for future decision-makers charged with sustainable maintenance of the Earth system and minimizing potential losses posed by natural disasters.

GEOSCIENCES INTERNATIONAL STRATEGIC PLAN 2011-2016

Introduction

The Geosciences traditionally have been conducted as an international endeavor. Coordinated major field campaigns, large user facilities, global observations and data exchange, and an interdisciplinary approach all are key elements of geosciences research. International relationships and activities are central to furthering our understanding of the earth system, and thus it is imperative to develop and/or strengthen international relationships at all levels, from individual scientists and science teams to governmental organizations, and non-governmental entities in order to enable future advances in geosciences.

Much like GEO's efforts in other focus areas (i.e., data, facilities, education and diversity), GEO's staff, through international work, seeks to provide multiple modes of support to advance the geosciences and realize a sustainable human future. This chapter describes GEO's goals and framework for strategic operations at different levels in the international arena for geosciences advancement.

GEO fully realizes that international geosciences activities do not exist in a vacuum. It is important to note that there are numerous activities in the Office of International Science and Engineering, in the Office of Polar Programs, and in other NSF Directorates, that may have implications for or connections to international Geosciences. GEO will continue to collaborate and consider the activities of other NSF organizations when possible and where appropriate. In addition, GEO's work in the international arena focuses on opportunities to leverage resources, especially given current fiscal and political realities, and to support work of high scientific merit which is transferrable and applicable to multiple geosciences issues and/or scales.

Mission and Vision

The mission for NSF's Directorate for the Geosciences is to support research in the atmospheric, earth, and ocean sciences. Along with the mission to support research also comes the responsibility to address the nation's need to understand, predict and respond to environmental events and changes in order to use the Earth's resources wisely.

GEO's international relationships and activities serve the geosciences at large by leveraging resources and expertise, providing real time data and understanding, and facilitating natural disaster preparedness, planning and response. The over-arching vision for GEO's international activities is to catalyze research excellence via international partnership and collaboration. The United States and NSF/GEO in particular must exercise a high level of leadership for

"The geosciences…are intrinsically international in scope. Deeply aware that geosciences research transcends national boundaries, GEO supports numerous international cooperative arrangements to enable researchers to develop scientific and financial capabilities needed to conduct research to understand more fully the origins of the Earth as well as its climate and environment. These arrangements include global programs in areas such as climate, seismology, meteorology, paleontology, geosphere–biosphere interactions, marine ecosystems, and ocean drilling. GEO is also involved with regional and bilateral arrangements with scientists, engineers, and institutions from numerous countries across all continents. Such arrangements vary from countries with scientific capabilities akin to our own to those with emerging economies facing specialized geographic issues." GEO Vision report (AC-GEO, October 2009).

- International Collaboration in the geosciences is essential
- Challenges are greater than any one country
- Enhances and complements strengths, interests and needs of U.S.
- Leverages existing and future international scientific capabilities and intellectual resources
- Provides mechanism to obtain new "global" data sets and access to critical research site

international research in the geosciences disciplines both within the United States and in the international research community. The challenge ahead is to place international activities, both current and future, into a strategic framework that optimizes investments, both human capital and fiscal resources, to facilitate discovery and innovation with significant societal impact.

Goals

The GEO International working group articulated the following goals for international geosciences activities:

- Catalyze research excellence via international partnership and collaboration.
- Leverage existing and future international scientific capabilities and intellectual resources.
- Provide mechanisms to obtain new "global" data sets and access to critical research sites.
- Promote educational excellence via international collaboration and development of a diverse U.S. science and engineering workforce prepared to engage with the global community.

Strategic Approaches

The scale and complexity of geosciences challenges requires global collaboration. To meet the goals articulated above, GEO approaches international collaborations from many angles and at many levels, including: researcher-to-researcher collaborations at group and individual levels; agency-to-agency cooperation within the United States; and government to government agreements with other nations. Sharing of facilities and other infrastructure is also an important aspect of international geosciences efforts.

Scientist to Scientist Level

Within the Geosciences there are countless international collaborations at the scientist-to-scientist level. These relationships and projects often grow out of shared need, shared research questions, and the inherently global/regional scale of geosciences problems. GEO is committed to maintaining a robust level of international scientist-to-scientist research collaboration efforts. These collaborations strengthen the U.S. workforce capacity by enriching the educational and career experience of geoscientists.

In addition, GEO views the scientist-to-scientist level of international activities as a key piece to building up networks and crossing disciplinary boundaries by pairing geoscientists with scientists and professionals from other disciplines. While the natural sciences can provide insight into how the environment may change, the social sciences provide the critical information about how people and societies behave in the face of change, and how various societal values may affect the policy decisions that are made in a given country. Given that such values and behavior may vary from one country to the next, it is important that the global dimensions of the social sciences relevant to the relationship with the environment are understood, and this can only be done through international cooperation.

U.S., Agency to Agency Level

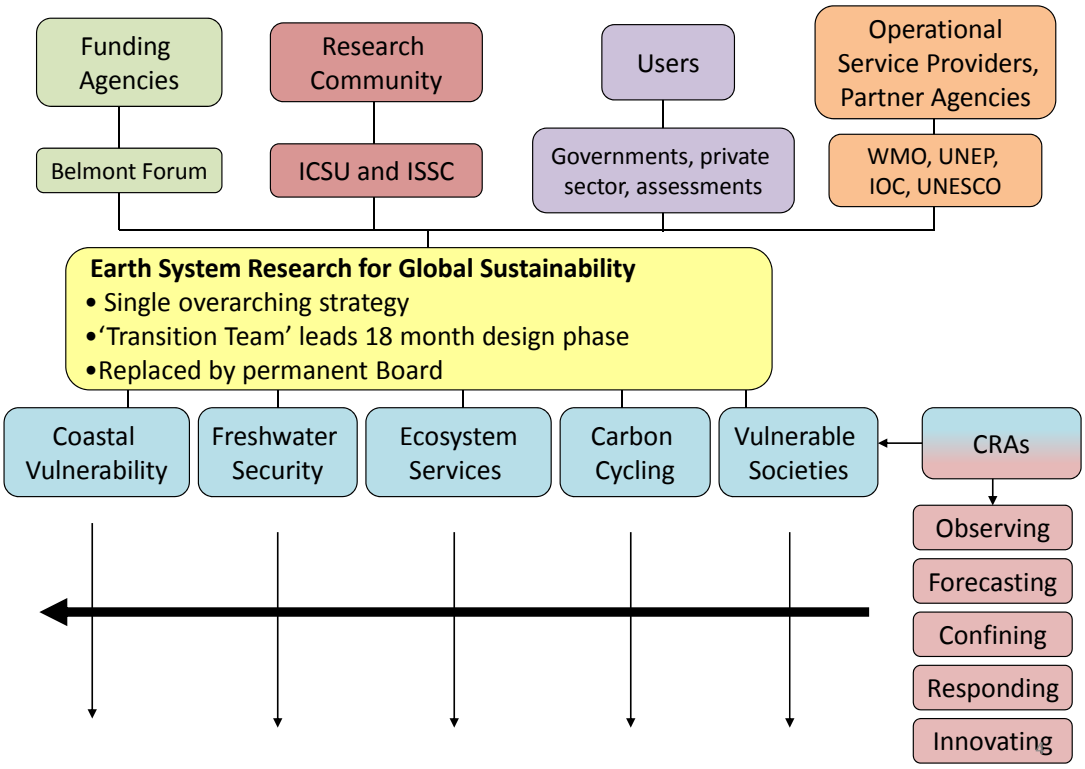
GEO continues to invest significant time and effort to coordinate international geosciences efforts of the federal family. GEO has long-term, well-established working relationships with key federal agencies such as Commerce (NOAA), Interior (USGS, USFS), Agriculture, and Energy. GEO actively seeks to improve collaboration at the agency-to-agency level to optimize financial and human capital.
The United States Global Change Research Program (USGCRP) coordinates and integrates federal research on changes in the global environment and their implications for society. USGCRP supports and engages in many international Global Environmental Change (GEC) activities including core support for international GEC program offices of the World Climate Research Program (WCRP), the International Geosphere-Biosphere Program (IGBP), the International Human Dimensions Program (IHDP), the Earth Systems Science Partnership (ESSP), DIVERSITAS and the SysTem for Analysis, Research and Training (START). These programs and their associated infrastructure provide an essential framework within which U.S. scientists lead, conduct and participate in a wide range of international global change research projects that advance key scientific objectives of the USGCRP and for which U.S. scientists provide leadership.

USGCRP began as a presidential initiative in 1989 and was mandated by Congress in the Global Change Research Act of 1990 (P.L. 101-606), which called for "a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." Thirteen departments and agencies participate in the USGCRP, which was known as the U.S. Climate Change Science Program from 2002 through 2008.

For USGCRP international engagement to help meet the goals of the USGCRP and its partner agencies, there needs to be agreement on the research priorities for the USGCRP to meet new GEC challenges at both the domestic and international scales. USGCRP must identify potential synergies with existing international partners and investigate collaborating with new programs as appropriate. For example, if the USGCRP wishes to more effectively coordinate GEC research in specific areas, it may be beneficial to look at cooperating with specific international research networks (e.g., Inter-American Institute for Global Change Research (IAI), Asia-Pacific Network for Global Change Research (APN), the African Network for Earth System Science (AfricanNESS)). To effectively participate in international efforts, the USGCRP should evaluate its international activities and articulate a clear role for itself, which will benefit the goals and missions of the USGCRP and its partner agencies.

Government to Government level (Bi-lateral and Multi-lateral agreements)

NSF GEO has been instrumental in establishing bi-lateral and multi-lateral agreements with other nations. These agreements, often in existence for decades, articulate roles and responsibilities for involved parties and represent a formal, visible commitment to excellence in geosciences research and education.
In addition to the various bi-lateral and multi-lateral agreements, international collaboration occurs via several national and international level research programs. These programs have contributed to promoting and encouraging research that has improved substantially the understanding of Earth system processes and the ways that the Earth system is changing. For example, in July 2009, the world's major funders of global change research, as well as the International Council for Science (ICSU), met at the Belmont House in Maryland, to consider how best to align financial and human capital towards delivering the environmental science knowledge base that society will need in the 21st century. This



Proposed Schematic for Alliance. Credit: Maria Uhle, GEO/NSF

group was dubbed the "Belmont Forum" and it operates as the Council of Principals for the broader International Group of Funding Agencies for Global Environmental Change Research (IGFA). In 2010, ICSU, the International Social Science Council (ISSC), Belmont Forum and IGFA combined their efforts to spearhead a proposal for a new "Alliance" among GEC stakeholders. This combined effort seeks to establish a single new top-level body with representation from the funders, researchers, operational agencies and users to deliver an overarching framework to coordinate environmental science research for sustainability.

The Belmont Challenge: To deliver knowledge needed for action to mitigate and adapt to detrimental environmental change and extreme hazardous events. This requires:

- Information on the state of the environment, through advanced observing systems;
- Assessments of risks, impacts and vulnerabilities, through regional and decadal analysis and prediction;
- Enhanced environmental information service providers to users;
- Inter- and transdisciplinary research which takes account of coupled natural, social and economic systems;
- Effective integration and coordination mechanisms, to address interdependencies and marshal the necessary resources.

In recent years, NSF/GEO has assumed leadership of efforts involving international research funding agencies, via IGFA and the Belmont Forum. NSF has been instrumental in reinvigorating dialogue, interaction, and collaboration of funding agencies in key industrialized and developing nations. NSF leadership in partnership with research funding organizations in other countries is seeking to move towards more active coordination of global change research funding. To be most valuable, the knowledge gained must be provided on time and space scales that enable effective decision-making and support equitable economic and social development. Harnessing various complementary international geosciences efforts will be a challenge in its own

right, but success will lead to greater coordination, leveraging, and advancement of science. International geosciences activities will promote cross-fertilization of ideas based on region-specific resources, and will provide access to international expertise, facilities, and data.

Resource and Infrastructure Sharing

Many geosciences challenges require data from the "global commons," such as the open ocean and its overlying atmosphere, as well as the polar regions. Field campaigns in these areas typically require the joint efforts of multiple countries to achieve critical mass in terms of comprehensiveness of observations, including data collection among multiple platforms, such as ships and/or aircraft.

Critical data are derived from observations and our scientists need to work with international partners to obtain not only data, but access to sites and to research platforms. For example, global observing systems, including both ground networks and satellites, are critical components of global environmental research. While many countries have their own capabilities, to provide a complete global data set, there is a need to develop an intelligently integrated and consistent system for observing, with transparency relative to aspects such as calibration, algorithms, and data utilization.

U.S. resource and infrastructure sharing for the purposes of international geosciences advancement has provided venues for direct participation and hands-on training on ships, in labs, with equipment and instruments for new generations of scientists. In addition, student and the general public are often engaged through distance learning initiatives, outreach displays for museums and education institutions, and lecture programs.

Challenges

Key challenges for the geosciences in the international arena include:

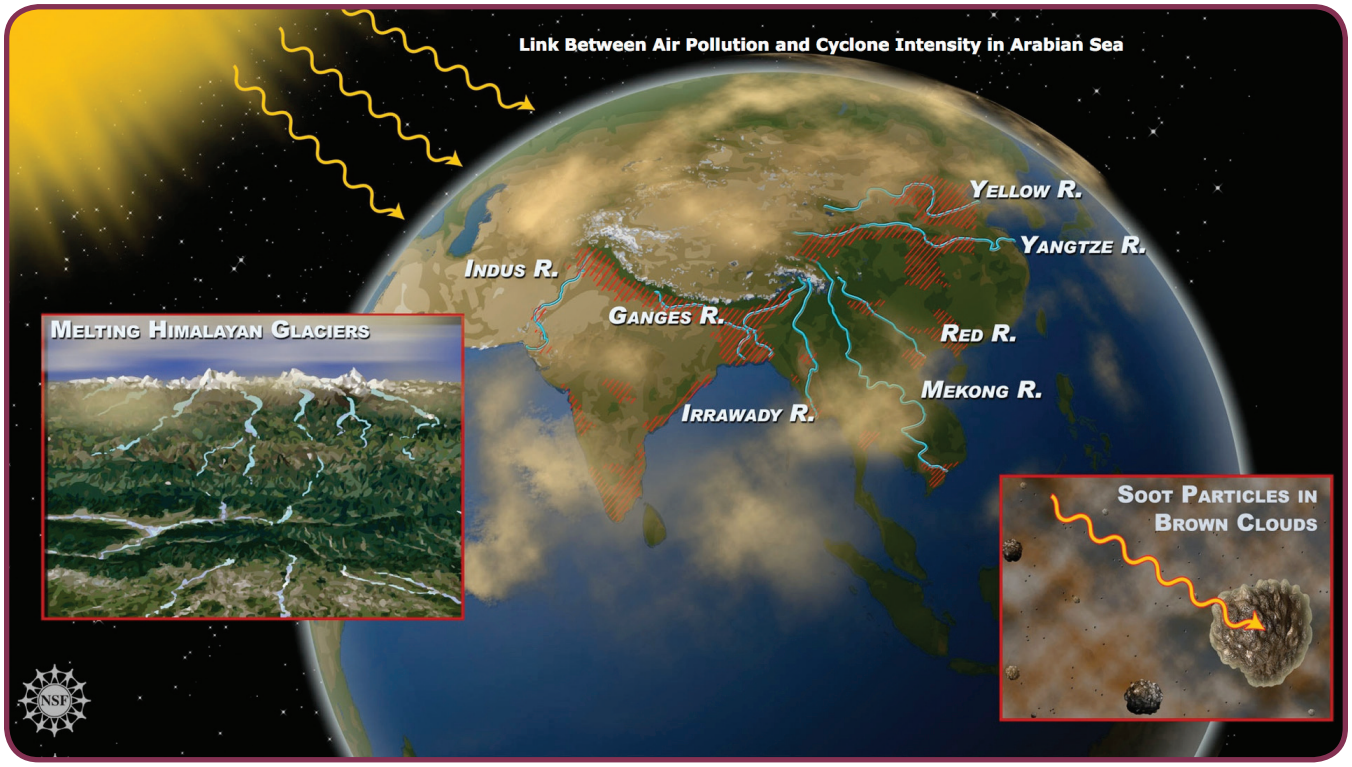
- Engaging the social science community as a fully integrated partner in environmental change research
- Development of a new generation of scientists capable of engaging with multiple research communities as well as doing fully integrated Earth system research
- Time and staffing resources necessary for communication among a large number of stakeholders.
- Ensuring compatibility and utility of different data systems and sets.

Conclusion

Scientific and engineering discovery and learning are worldwide phenomena. Centers of research excellence are emerging across the globe and new ideas and research are resulting from intellectual interactions of people with diverse backgrounds. Consequently, U.S. scientists and engineers must be globally engaged and able to operate effectively in teams/networks with partners from different nations and cultural backgrounds. International partnerships are, and will be, increasingly indispensable in addressing critical geosciences issues. AC GEO believes that the GEO Directorate can and should take a leadership role both within the U.S. government and internationally to define and then implement the science activities that will push the frontiers back and make a meaningful and lasting impact on human society.

GEO leadership should examine opportunity spaces to inform its policies, procedures, and priorities, including:

- Ways to establish research opportunities jointly funded by international agencies.
- Mechanisms for U.S. researchers to participate in international sciences efforts (e.g., cost-sharing for such participation).
- Funding for international supplements to currently funded NSF projects in the U.S.
- Greater opportunity for international student participation in its programs (or for US students to participate in international projects funded by other countries/agencies).
- Increased use of international reviewers for proposals.



Credit: Nicolle Rager Fuller, National Science Foundation

Credit: UCAR, Photo by Carlye Calvin

GEOSCIENCES DATA AND INFORMATICS STRATEGIC PLAN 2011-2016

Introduction

As modern science becomes increasingly integrative, multi-disciplinary, multi-scale and complex, the data and computational intensity of the research endeavor are compounded. The Geosciences are at the crux of this new data-enabled sphere of science. New types of measurements are being made or are planned to measure the Earth system across a broad range of spatio-temporal scales required to comprehend its full complexity: from the core to its crust, the depths of the ocean and sub-seafloor, all the way to the edges of space.

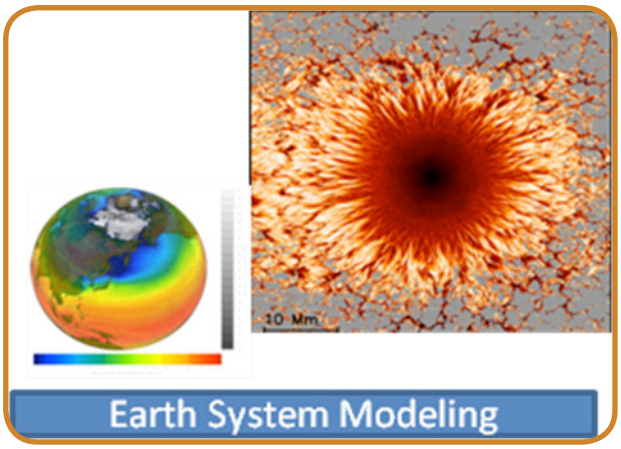
Many new systems for monitoring or modeling Earth systems have come on-line and more are planned, each producing copious amounts and types of data. The trend is clear; geoscientists are increasingly engaged in data intensive science and investigation, data management, and long-term data access and storage.

NSF and GEO staff recognize the multifaceted challenges of modern, data-intensive science and education and envision an environment where low adoption thresholds and new capabilities act together to greatly increase the productivity and capability of researchers and educators working at the frontiers of Earth system science. NSF seeks transformative concepts and approaches to create integrated data management infrastructures across the geosciences. The Directorate for Geosciences (GEO) Data and Informatics workgroup is examining activities, directorate-wide, that are undertaken to add value to data collected, to increase researchers access to and more productive use of data, and to provide the science and education communities with capabilities previously unavailable.

Vision of a GEO Cyberinfrastructure (CI) Framework

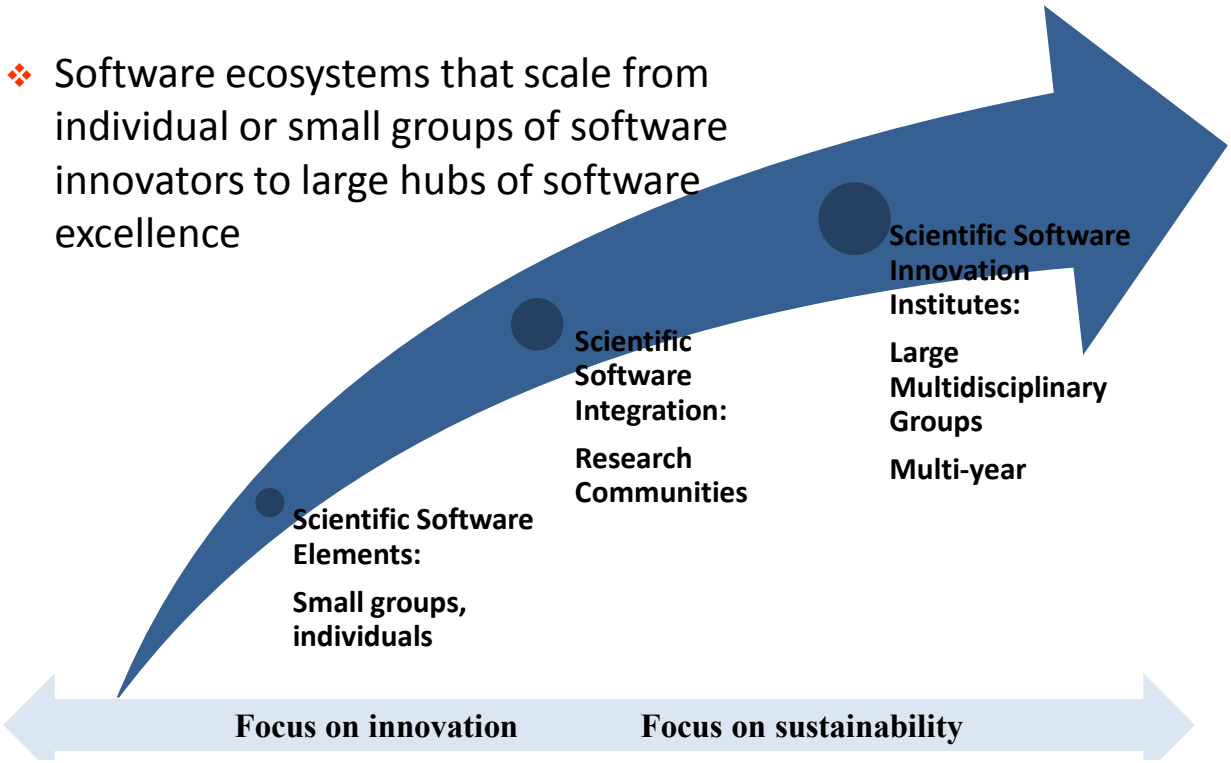
The GEO Vision document presents a call to action for the geosciences community. Over the next decade, the geosciences community committed to developing a framework to understand and predict responses of the Earth as a system–from the space-atmosphere boundary to the Earth's core, including the influences of humans and ecosystems.

This vision is an ambitious scientific endeavor that will require significant advances in the cyberinfrastructure in the next decade. Taking input from a wide array of workshops, reports and community feedback, GEO sees a common need for increased data management, new computational capabilities, and improved connections between researchers and instrumentation. GEO's cyberinfrastructure investments must provide a framework of integrated and interactive services that support understanding and prediction of the Earth system as a whole. The end goal includes creating a more informed public, a CI and GEO savvy workforce,



Scalable Software Development Environments

- Software ecosystems that scale from individual or small groups of software innovators to large hubs of software excellence



and broader participation in understanding the Earth system. This chapter provides an overview of GEO's portfolio of data and informatics practices and describes how these practices are essential to the realization of GEO Vision and the NSF Strategic Plan.

This cyberinfrastructure framework includes four critical elements.

1. A set of robustly integrated and interactive services that transcend fields and accelerate discovery of a complex, multi-scale Earth System
   - Implications of new data types to new applications;
   - Enhanced capabilities for finding, using, and integrating information to accelerate the pace of discovery.
   - New ways of thinking about software, visualization and computational tools
2. Digital access in an interoperable framework
   - Provides a network that is open, extensible and sustainable
   - Includes Observations, Simulations, Collaborations, and Sharing of information.
3. Transparent data transfer from the field into data systems and applications
4. The integration of research and education through training paradigms and new modes of learning and training.

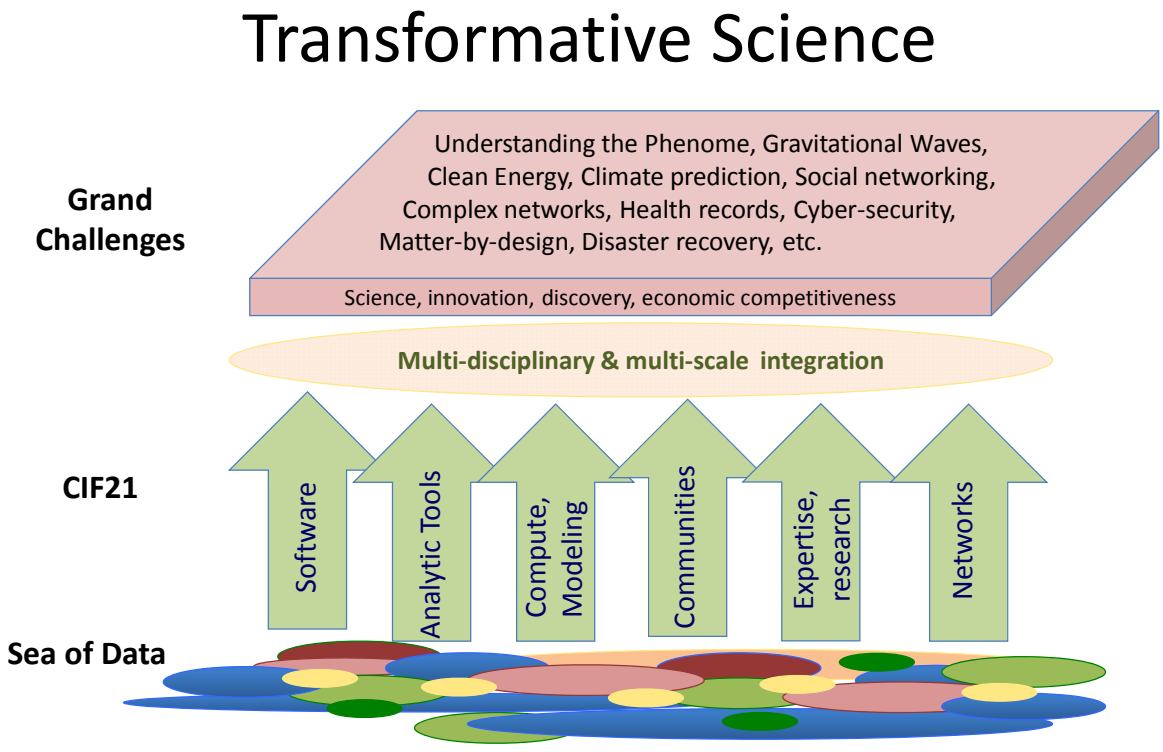
This strategic framework for GEO's cyberinfrastructure portfolio is not developed in a vacuum. NSF recently completed a comprehensive survey through its Advisory Committee on Cyberinfrastructure, including reports on high performance computing, data and visualization, campus bridging, cyber-learning, and CI grand challenges. A set of 25 workshops taskforces and reports have resulted in a

long-term NSF focus on cyberinfrastructure for the 21st century. The guiding principle is the need for a comprehensive and integrated cyberinfrastructure that transforms research, innovation and education. The investment aims at the shared governance of national cyberinfrastructure for science and engineering, leveraging common methods, approaches and applications, and catalyzing CI investments across NSF. The focus on computationally and data-intensive science is framed in 4 themes, Data-Enabled Science, New Computational Infrastructure, Connection to Facilities, and Community Research Networks.

Goals

NSF places significant emphasis on computational and data-rich science and engineering, with the goal of providing a sustainable, community-based and open cyberinfrastructure for researchers and learners. This is a major challenge because the number and volume of data sets have grown to proportions well beyond the range of applicability of traditional data handling tools. Transformative approaches and innovative technologies are needed for heterogeneous data to be integrated, made interoperable, explored and re-purposed by researchers in disparate fields and for myriad uses across institutional, disciplinary, spatial and temporal boundaries.

GEO is well-positioned to support developments in all of these areas. Because of its long history of CI investments across geosciences domains, GEO has the basis to connect the decadal goals of Geo Vision to the NSF-wide cyberinfrastructure plans. This connection requires understanding and building upon the community's current resources and requirements, defining best practices for data sharing, tool development and developing community support.



Credit: Cliff Jacobs, GEO/NSF.

The focus areas of CIF21 provide a natural organization for GEO's cyberinfrastructure goals outlined in the section below. GEO's decadal CI implementation plan is informed by the following guiding principles.

- Community input and requirements will guide strategic investments;
- Data policies are essential for effective construction and use of cyberinfrastructure;
- Active collaborations are needed within NSF and with partners in other agencies, industry and internationally.

Goal 1: Data-Enabled Science

Data-enabled science is practiced with the hardware, software, and human capital infrastructure to increase the interoperability of data sets.

Objectives:

- Query the geosciences community on managing the full lifecycle of data
- Develop a framework for open and easy access of geosciences data
- Integrate observation with model data to improve understanding and prediction of the Earth system
- Develop the software, hardware, and networking capability to analyze, manipulate, visualize, and share large and complex data sets
- Connect physical data, historical data, and metadata into cyberinfrastructure frameworks

Goal 2: New Computational Infrastructure

A new computational infrastructure is developed that is widely available, with new and enhanced computational platforms, tools, and data centers that allow integration of Earth sub-system models into a whole Earth model.

Objectives:

- Integration of observation with model data to improve understanding and prediction of the Earth system
- Support for facilities or institutes with expertise to produce robust, sustainable software relevant to the geosciences.

Goal 3: Connection to Facilities

Improving connections to facilities is essential to study the whole Earth System. Foremost for geosciences is the need to facilitate transparent data transfer from the field into data systems and applications.

Objectives:

- Infrastructure to enable the sharing of observational data for disparate and new research endeavors through local and global connections to observing networks and data systems
- Development of capabilities and technology to more efficiently retrieve data from the field, leading to real-time data gathering, alleviating data retrieval missions
- Development of the software, hardware, and networking capability to analyze, manipulate, visualize, and share large and complex data sets.

Goal 4: Networks

Research networks are created to enhance multidisciplinary research through shared data, modeling, and education.

Objectives:

- Sustained educational and training programs utilizing traditional and new educational paradigms to create a computationally savvy workforce and serve multi-disciplinary science.
- Hardware, software, and human capital infrastructure to increase interoperability of data sets.

Strategic Approaches: EarthCube

GEO envisions a long-term iterative process to achieve an integrated CI framework that provides multiple modes of support to the scientific community. GEO continues to make substantial investments in collecting data through NSF-supported research facilities and projects, and in helping the geosciences community utilize data collected by other entities around the world. Similarly, NSF's Office of Cyber Infrastructure (OCI) makes substantial investments in advanced high-performance computing, data infrastructure, software development, virtual organizations and networking. The two organizations are working to integrate these data and technologies in an open, adaptable and sustainable framework (an "EarthCube") to enable transformative research and education in Earth System Science; foster common data models and data-focused methodologies; develop next generation search and data tools; and advance application software to integrate data from various sources and advance knowledge.

The primary goal is to create a prototype EarthCube system for an agile and robust geosciences-integrating architecture with an inclusive governance paradigm. Through the EarthCube system, NSF seeks to transform the conduct of research in geosciences by supporting community-based cyberinfrastructure to integrate data and information for knowledge management across the geosciences.

NSF is actively seeking community input and has hosted a series of webinars to rapidly facilitate the early stages of novel approaches for this system. NSF hosted an interactive "charrette" meeting in November 2011 from which actionable ideas emerged to help define future developments of this system.

From late 2011 through early 2012 NSF has been working to codify community-influenced designs, governance structures, and innovative approaches to EarthCube. EAGER grants will be supported for development and design of transformative concepts.

A second EarthCube Community Event is scheduled for June 2012 to further the design development through a process of intense design and revision with the intention of funding prototype systems.

Following the second EarthCube Community Event, Earth Cube will enter a prototype development stage to develop system capabilities, while considering usefulness to a broad range of geosciences users and to create community governance founded on trust and common values.

The iterative process will continue with other milestones, and opportunities for the community to focus their efforts.

Conclusion

Understanding and managing this unprecedented amount of data, including data from new instruments, sensors, sociological data and historical data, will require data-sharing, software visualizations, new algorithms, methods and tools, and real time access to instruments and data. Necessary resources will include new types of infrastructure for storage, curation, and preservation. Additional challenges will revolve around creating interdisciplinary partnerships across networks, and interoperability among data sets, as well as managing the speed of technological and computational advances.

An effective approach to overcoming challenges must constructively engage major NSF-funded observational facilities as well as a diverse range of geosciences data collections and collectors, find commonalities for a data model(s), form sustained partnerships with other entities that collect data (e.g. other Federal and international agencies), and foster symbiotic relationships with industry that will be essential for NSF to consider investment in a prototyping enterprise. It is expected that collaborative efforts will emerge among researchers with keen interest in, and knowledge of, geosciences data collection and use.

Geospatial data, metadata, enabling software/hardware, and training are essential elements relied on by much of the geosciences community and must be optimized to increase researchers productivity and capability. Science enabled by data and supporting cyberinfrastructure will be central to furthering our understanding of the Earth system.

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