National Aeronautics and Space Administration

Earth Science Enterprise Strategy

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

How is the global Earth system changing?
What are the primary causes of change in the Earth system?
How does the Earth system respond to natural and human-induced changes?
What are the consequences of change in the Earth system for human civilization?
How will the Earth system change in the future?

The Earth Science Enterprise mission:
to understand and protect our home planet
by using our view from space to study the Earth system
and improve prediction of Earth system change.

http://earth.nasa.gov
October 1, 2003

A Message from the Associate Administrator for Earth Science

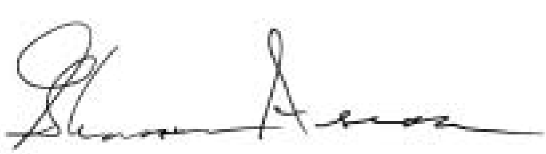
Improving life on planet Earth is foremost in NASA's Vision, and the central work of NASA's Earth Science Enterprise. Using the vantage point of space, we gain an understanding of our home planet that could never be achieved if we were bound to Earth's surface. From space, we see Earth's complexity, dynamism, and fragile balance. We are compelled by both the beauty and utility of viewing Earth from space to understand and protect our home planet, the only known harbor of life in the solar system.

NASA research yields information about Earth's land, atmosphere, ice, oceans and life that is obtainable in no other way. Global changes require global-scale observations and models, and many regional and local changes are only truly understood when seen in their global context. Research conducted by the Earth Science Enterprise advances the interdisciplinary field of Earth system science and contributes to NASA's mission to understand and protect our home planet.

We continue to transform the Earth Science Enterprise in light of new scientific understanding, advances in technology, and emerging national priorities. Our research and Earth observation programs engage the issues at the frontiers of science and the forefront of societal concern. The wealth of Earth system data we provide to Government agencies, universities, and private industry allows for better research, exploration, and improvements in essential services such as weather forecasting, seasonal climate prediction, climate change assessments, aviation safety, natural resources management, agricultural management, and infrastructure planning.

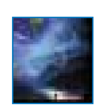
The Earth Science Enterprise plays a vital role in three key challenges facing America and the world today: climate change, homeland security, and educating the next generation of explorers. In the area of climate change, the Enterprise contributes research for national policymaking and is a leading participant in interagency climate change science and technology programs. The Enterprise is helping create a more secure world through targeted collaborations that extend our Earth system knowledge to Federal agencies, State and local governments, industry, and international organizations. Finally, we are helping transform Earth science instruction in our Nation's schools by providing new perspectives on Earth's interconnected systems of atmosphere, oceans, continents, ice, and life.

This Earth Science Enterprise Strategy discusses our approach to these great endeavors and outlines the key program components of the Earth Science Enterprise—Research, Observation and Information Management, Advanced Technology, Applications, and Education. To NASA, Earth science is science for society. We are honored to play a leadership role in understanding and protecting our home planet.

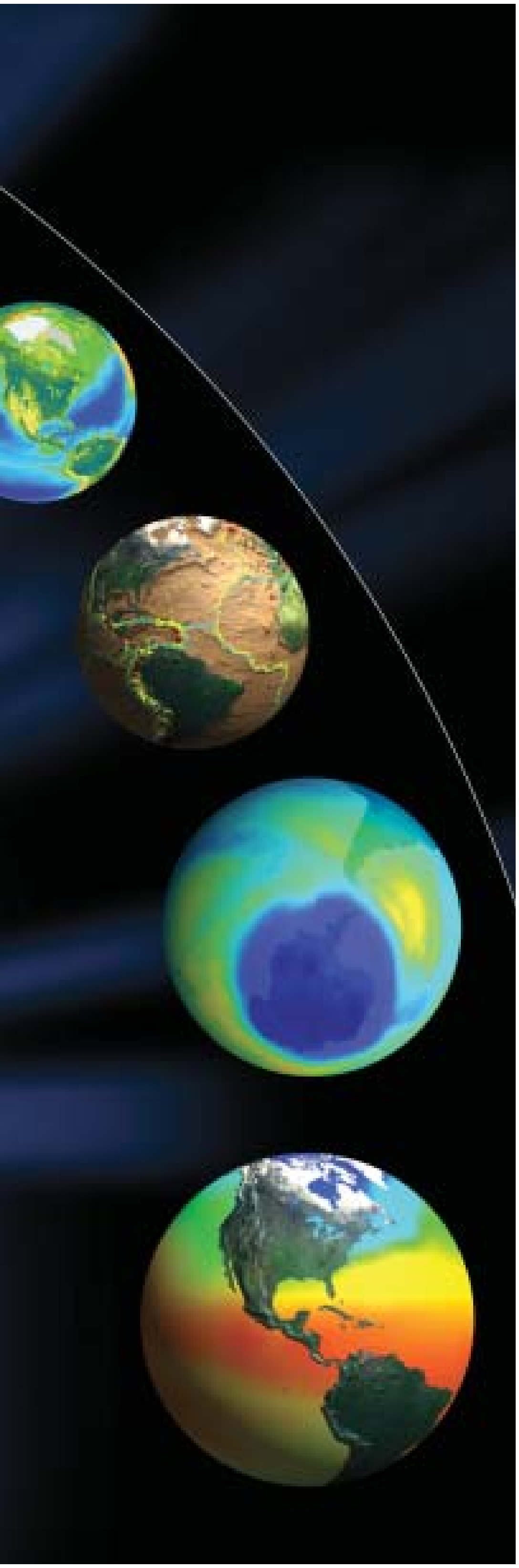


Ghassem R. Asrar, Ph.D.
Associate Administrator for Earth Science

Table of Contents



1 The Earth Science Enterprise in NASA's Vision and Mission



1 The Earth Science Enterprise in NASA's Vision and Mission

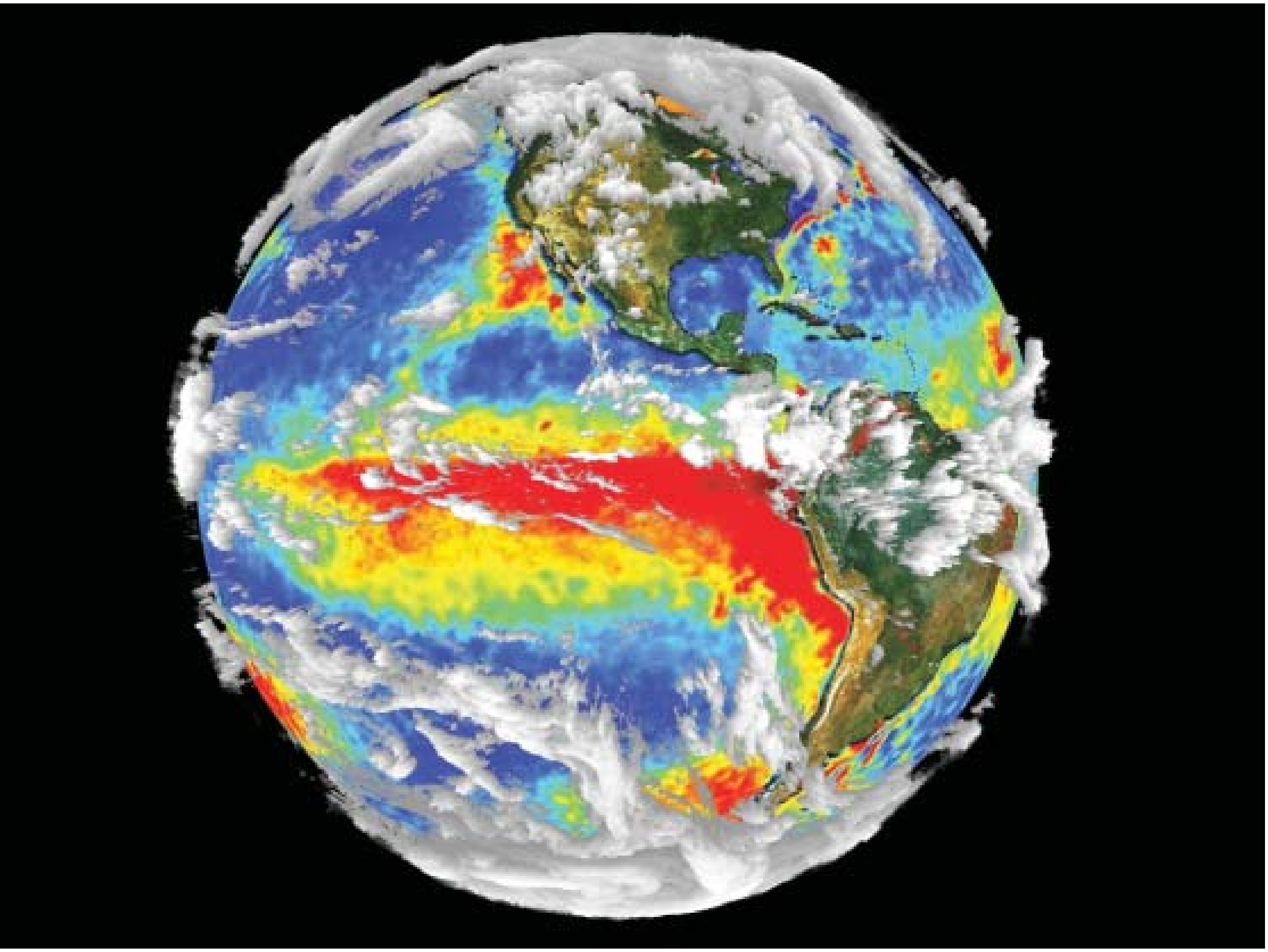
The NASA Vision—
To improve life here,
To extend life to there,
To find life beyond.

The NASA Mission—
To understand and protect our home planet,
To explore the universe and search for life,
To inspire the next generation of explorers
. . . as only NASA can

Life is the common thread through NASA's Vision and Mission. While we seek to extend life to other places in the solar system and search for life beyond Earth, we know that improving life here is our first and highest calling. From the first weather satellite in 1960 to today's capability to observe all major components of the complex Earth system, NASA's view of our home planet is employed in valuable ways to improve life on Earth.

The Earth Science Enterprise mission: to understand and protect our home planet by using our view from space to study the Earth system and improve prediction of Earth system change.

The solid scientific and technological foundation laid by NASA over the past 40 years enables the Earth Science Enterprise to play a leading role in NASA's Mission to understand and protect our home planet. We use NASA's unique capabilities to understand and protect our home planet by using our view from space to study the Earth system and improve prediction of Earth system change. The Earth Science Enterprise, working with its domestic and international partners, provides accurate, objective scientific data and analysis to advance our understanding of Earth system processes and to help policymakers and citizens achieve economic growth and effective,



Seeing Earth through the lens of science. This Earth image is a compilation of several data sets of the type produced by NASA's Earth Observing System, including cloud cover, vegetation, fires, and sea surface temperature. From the latter, the 1997-98 El Niño is clearly visible. (Credit: R.B. Husar, Washington University

responsible stewardship of Earth's resources. We pursue answers to the fundamental question, "How is Earth changing, and what are the consequences for life on Earth?"

The Earth Science Enterprise also has a supporting role in NASA's Mission to explore the universe and search for life. Our understanding of Earth system processes such as atmospheric dynamics, crustal motion, and the imprint of life on the atmosphere is a paradigm for understanding other planets. Our observing technologies are precursors for those to be deployed elsewhere in the solar system, and our data and models can be configured to study many planetary and solar processes. In conjunction with the Space Science Enterprise, we explore the Sun-Earth connection to reveal solar influences on Earth's climate.

The Enterprise has an essential role in NASA's Mission to inspire the next generation of explorers. The Earth system science concept pioneered by NASA is beginning to revolutionize the way Earth science is taught from elementary to post-graduate education. We inspire students of all ages by sharing the view from space and discoveries of how continents, oceans, atmosphere, ice and life interact to produce changes in climate, weather, and natural hazards. NASA's unique contributions to Earth system science include:

• Creating the ability to study the Earth as an integrated physical and biological system. The Agency is pioneering new remote sensing capabilities from a variety of vantage points. Global-scale changes require a global perspective, and local and regional changes can only be fully understood in their global context.

• Addressing fundamental scientific questions with an "end-to-end" approach that integrates Earth observation, interdisciplinary research, and Earth system modeling, providing comprehensive results to Earth science questions that inform policy and economic decisions.

• Advancing remote sensing technology and computational modeling for scientific purposes, and facilitating the transition of mature observations and technologies to partner agencies that provide essential services using Earth science information.

• Forging domestic and international partnerships to explore the complex Earth system. NASA has the program management and system engineering expertise to help lead complex, multi-partner research endeavors as well as make unique contributions to those led by other nations and organizations.

In these ways and more, we conduct Earth system observation, research, and knowledge transfer—as only NASA can.

Coastal zones are the sites of some of the most important, productive, and unique ecosystems on Earth and are home to abundant and diverse flora and fauna. Because of these valuable and accessible assets, coastal regions are centers of human population (more than 1 billion people worldwide) and commerce. NASA satellites observe coastal zones globally, enabling study of sea level change, ocean temperature and circulation, and land use change in these vital regions.

2 Strategic Context and Approach

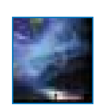
2 Strategic Context and Approach

The Earth Science Enterprise plans its scientific and programmatic endeavors in accord with NASA's Vision and Mission, in the context of current scientific, societal and national imperatives. (See appendix 1 for further information on the Agency's overall strategic planning context.)

2.1 Scientific, Societal, and National Imperatives

Earth is the only planet we know of that sustains life. Life on Earth is critically dependent on the abundance of water in all three phases—liquid, vapor and ice. Carbon, existing in a variety of forms, is the very basis of life, and its greatest reservoir. In the atmosphere, carbon fully oxidized as carbon dioxide, fully reduced as methane, and in particulate form as black carbon soot produces the greenhouse effect making Earth habitable. Earth's atmosphere and electromagnetic field protect the planet from harmful radiation while allowing useful radiation to reach the surface and sustain life. Earth exists within the Sun's zone of habitation, and with the moon, maintains the precise orbital inclination needed to produce our seasons.

These remarkable factors have contributed to Earth maintaining a temperature range conducive to the evolution of life for billions of years. The great circulation systems of Earth—water, carbon and the nutrients—replenish what life needs and help regulate the climate system. Earth is a dynamic planet; the continents, atmosphere, oceans, ice, and life ever changing, ever interacting in myriad ways. These complex and interconnected processes comprise the Earth system, which forms the basis of the scientific research and space observation that we refer to as Earth system science.



Mt. Etna, Europe's largest and most active volcano, erupted in October 2002. NASA satellites detected the heat signature, plume and resulting forest fires.

In Earth system science, researchers take a contextual approach to scientific inquiry—they explore extreme weather events in the context of changing climate, earthquakes and volcanic eruptions in the context of tectonic shifts, and losses in biodiversity in the context of changes in Earth's ecosystems. This leads to the exploration and discovery of causes and effects in the environment. For instance, Earth system scientists have linked ocean temperatures and circulation to the moderate climate of northern Europe relative to its latitude, the annual changes of ozone concentration over Antarctica with the production of industrial refrigerants in the Northern Hemisphere, and the physics and chemistry of the atmosphere to air quality and fresh water availability.

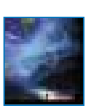
Research on Human Dimensions

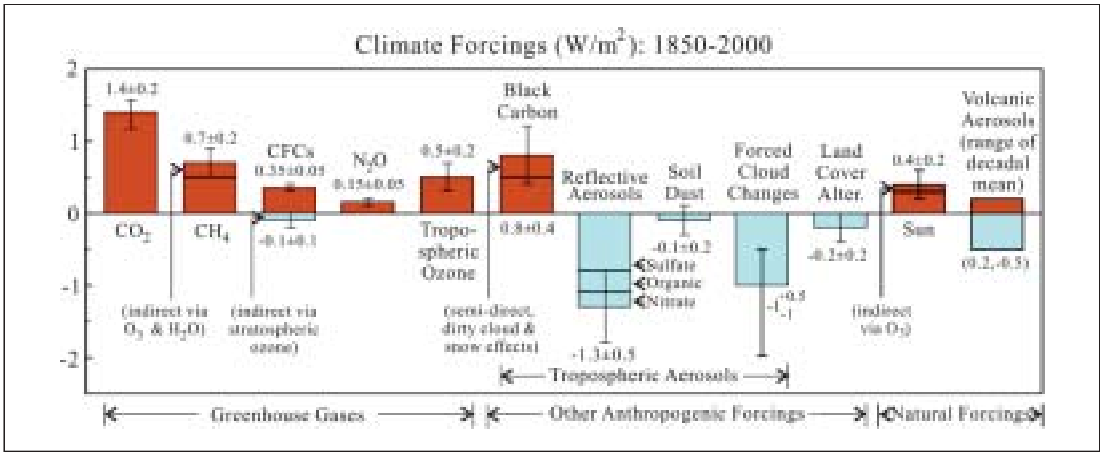
The human dimensions of environmental change are important elements in understanding the Earth as a system. Social science research is primarily conducted by other Federal agencies, such as the National Science Foundation, the Environmental Protection Agency, and the Department of Health and Human Services. The Enterprise works directly with these agencies to develop the data and information from NASA's observatories and decision support systems for their applications. Additionally, the results of this important research that are relevant to global change and Earth system science are distributed through the Socioeconomic Data Archive Center (SEDAC), located at Columbia University. As part of the integrated NASA Earth science data and information system, SEDAC provides geospatial data and information vital to understanding the Earth as a system and represents a focal point for interaction between scientific efforts at NASA and those at other agencies, as well as communication with the public and social science communities.

From space we can view the Earth as a whole system, observe the net results of complex interactions, and begin to understand how the planet is changing in response to natural and human influences. For example, Earth system science has begun to understand and quantify the effects of "forcings" on the climate system produced by the Sun's solar variability and the atmosphere's increasing concentrations of carbon dioxide and aerosols. The fact that researchers detect not just variability but trends in the key measures of Earth systems make it imperative for us to ask, "How is the Earth system changing, and what are the consequences for life on Earth?"

With the power to observe Earth from space and to employ these observations in computational models of Earth system processes, NASA and its partners are gaining new insight into how the Earth system works. This understanding has provided confidence that we are on the verge of establishing predictive capabilities for the Earth system that will permit the assessment of the consequences of change for life on Earth. Over the next decade, NASA's Earth Science Enterprise and its partners will enable reliable prediction of:

- Climate variability and change, and scientific assessment of the impacts of changes in global sea level and ocean circulation, regional temperature, precipitation, and soil moisture
- Recovery of Earth's atmospheric ozone shield and assessment of the quality of the air we breathe





NASA research on the factors influencing climate change in the atmosphere (called "forcings") has led to new options for consideration by policymakers. In this display of climate forcings, it is apparent that taken together, methane, tropospheric ozone and black carbon aerosols have as much influence on climate change as carbon dioxide. They may also be more economical to constrain. (Credit: Hansen and Sato, *Proceedings of the National Academy of Sciences*, Vol. 98 No. 26, December 18, 2001)

- Global terrestrial and ocean biological productivity, ecosystem health, and interactions with the climate system, and the implications for food and fiber production

- Extended weather patterns, and early formation and the probable pathway of severe storms and hurricanes for planning evacuations and protecting life and property

- Seasonal flooding, droughts and water supply by region globally, and their impact on agriculture and fire hazards

- Volcanic eruptions on monthly time scales and estimation of earthquake probabilities for selected tectonic zones for the protection of life and property

Naturally occurring and human-induced changes in the Earth system have profound consequences for our Nation and the world. Severe weather events caused nearly $12 billion in damages in 2001 alone. The 1997-98 El Niño had impacts in the United States on the order of $25 billion. In the summer of 2000 alone, wildfires burned 8.4 million acres in the western United States. The Federal Government obligated approximately $7 billion dollars through FEMA to fund recovery from the 1994 Northridge earthquake. A repeat of the 1906 San Francisco earthquake today could cause damage estimated to be $500 billion. NASA's Earth observing capabilities and scientific research, coupled with those of our partners, are helping society determine and manage these risks. The recent report "Reducing Disaster Vulnerability Through Science and Technology" from the interagency Subcommittee on Disaster Reduction (of which NASA is a member) documents these risks. Industries sensitive to weather and climate change, from agriculture to transportation, comprise $3 trillion dollars of economic activity annually, about one-third of U.S. gross domestic product. Knowledge of the Earth system resulting in improved environmental prediction will significantly benefit these industries.

Earth observation from space and the scientific understanding such observations yield about Earth system processes are essential to predicting future change, and to making sound, scientifically based economic and policy decisions on matters related to environmental change. The U.S. Climate Change Science and Technology Programs, the U.S. Weather Research Program, interagency disaster mitigation efforts, various Federal natural resources management initiatives, homeland security, and infrastructure management all rely on the unique observations, technologies, and research that NASA provides and enables. (Earth Science Enterprise roles in and alignment with the U.S. Climate Change Science and Technology Programs are summarized in appendix 5.) NASA is an essential part of the national contribution to international research endeavors such as the International Geosphere-Biosphere Program, the World Climate Research Program, and to sponsoring organizations such as the International Council of Scientific Unions and the World Meteorological Organization, as well as major scientific assessments of global change.

NASA's scientific research, technological innovations, and Earth observation capacities allow the Agency to address questions at the frontiers of science that have profound implications for the future of our planet.

2.2 Past Progress, Future Prospects

NASA's Earth-observing satellites and sponsored research have led scientists to view the Earth as a system—a dynamic set of interactions among continents, atmosphere, oceans, ice, and life. This profound realization gave rise to the birth of the new interdisciplinary field of Earth system science. This way of studying the Earth is critical to understanding, for example, how global climate responds to the forces acting on it.

From the 1960s through the 1980s we developed the technology to view the Earth globally from space, focusing on individual components of the Earth system. This launched an era of rich scientific discovery, including the discovery of the processes behind Antarctic ozone depletion; the Earth's response to incoming solar radiation; and the extent, causes, and impacts of land use and land cover change.

In the 1980s and 90s we developed the interdisciplinary field of Earth system science, and began to survey the Earth system in its entirety, leading to the deployment of the Earth Observing System (EOS). During this period, scientists used space-based observations, coupled with suborbital and in situ observations, to uncover the mechanics behind the El Niño-La Niña cycle and begin modeling the climate system in a meaningful way. For the first time, scientists were able to measure the global distribution of atmospheric aerosols and related changes over seasons and years.

In the new century, we are completing the first phase of the EOS (figure 2.1) and securing the partnerships needed to achieve and sustain a long-term continuum of climate data. We are inventing new capabilities and technologies to close the gaps in our knowledge of the Earth system, such as new methods to measure motions of the Earth's crust and interior that lead to earthquakes and volcanoes and sensors to detect changes in the distribution of gas and aerosol particles in the atmosphere regionally and globally over days, months, years, and decades. Examples of these scientific results are listed in

Figure 2.1

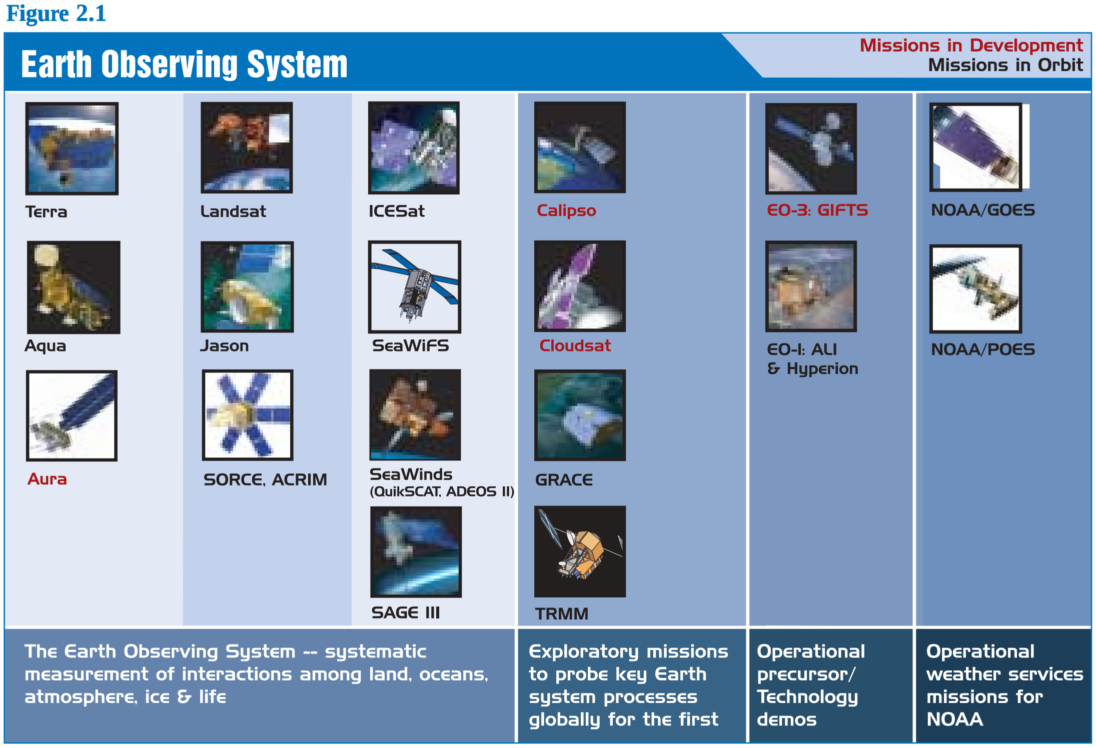
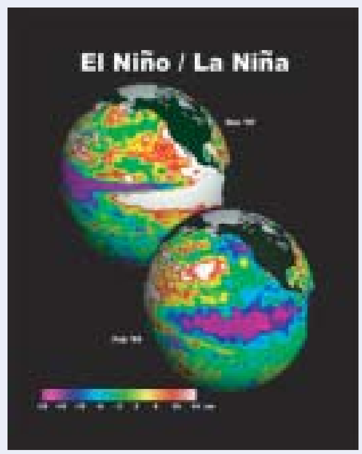


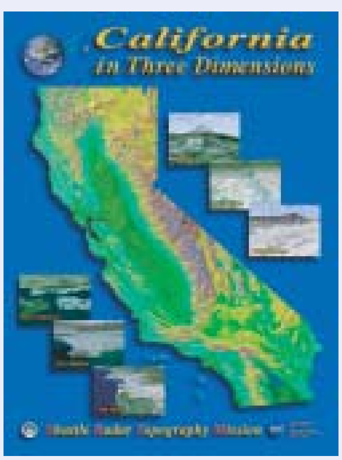
figure 2.2. We are gaining an understanding of the transformation of the land surface as populations and economies move and grow. The Nation now has a system of satellites with the ability to characterize the current state of the Earth system. In collaboration with our research partners, we will pursue an understanding of the Earth system through the integration of satellite, suborbital and surface measurements in conjunction with models that simulate links and feedback between Earth system processes. In the years ahead, Earth-orbiting satellites will evolve into constellations of smart satellites that can be reconfigured based on the changing needs of science and technology. From there we envision an intelligent and integrated observation network composed of sensors deployed in vantage points from the subsurface to deep space. This "sensorweb" will provide on-demand data and analysis to a wide range of end users in a timely and cost-effective manner. These data and information products will be used in Earth system models by NASA, NOAA, NSF, and DOE to assess and predict Earth system change. This observation system will have many practical benefits for scientific research, national policymaking, and economic growth.

Figure 2.2

Taking the Pulse of Our Home Planet

- Measuring and monitoring continental drift and plate tectonics, and understanding their impact on natural hazards, earthquakes and volcanoes
- Capturing and documenting dynamics of Earth's Ozone layer and understanding the effects of its depletion on exposure to UV radiation at the Earth's surface
- Capturing and documenting global ocean circulation and its role in Earth's weather and climate
- Documenting land cover change at global and regional scales in response to natural and human influences
- Capturing the seasonal dynamics of land vegetation and ocean phytoplankton, and their capacity to cycle carbon through the Earth system and in food and fiber production
- Mapping the 3-D structure of storms and hurricanes and their risks to human safety, property, and infrastructure





- Mapping Greenland and Antarctic ice sheets in 3-D with unprecedented accuracy to understand their role in Earth's weather, climate and sea level change
- Measuring the Earth's Radiation budget and its variations with unprecedented accuracy to assess its impacts on Earth's climate and weather
- Measuring Earth's gravity field and its variations over time with unprecedented accuracy to assess its impacts on ocean circulation and Earth's climate
- Measuring the distribution of aerosols and clouds and assessing their roles in Earth's climate and energy budget
- Mapping the Earth's surface in 3D with unprecedented accuracy and resolution and using this knowledge to improve understanding of floods, landslides, earthquakes & volcanoes

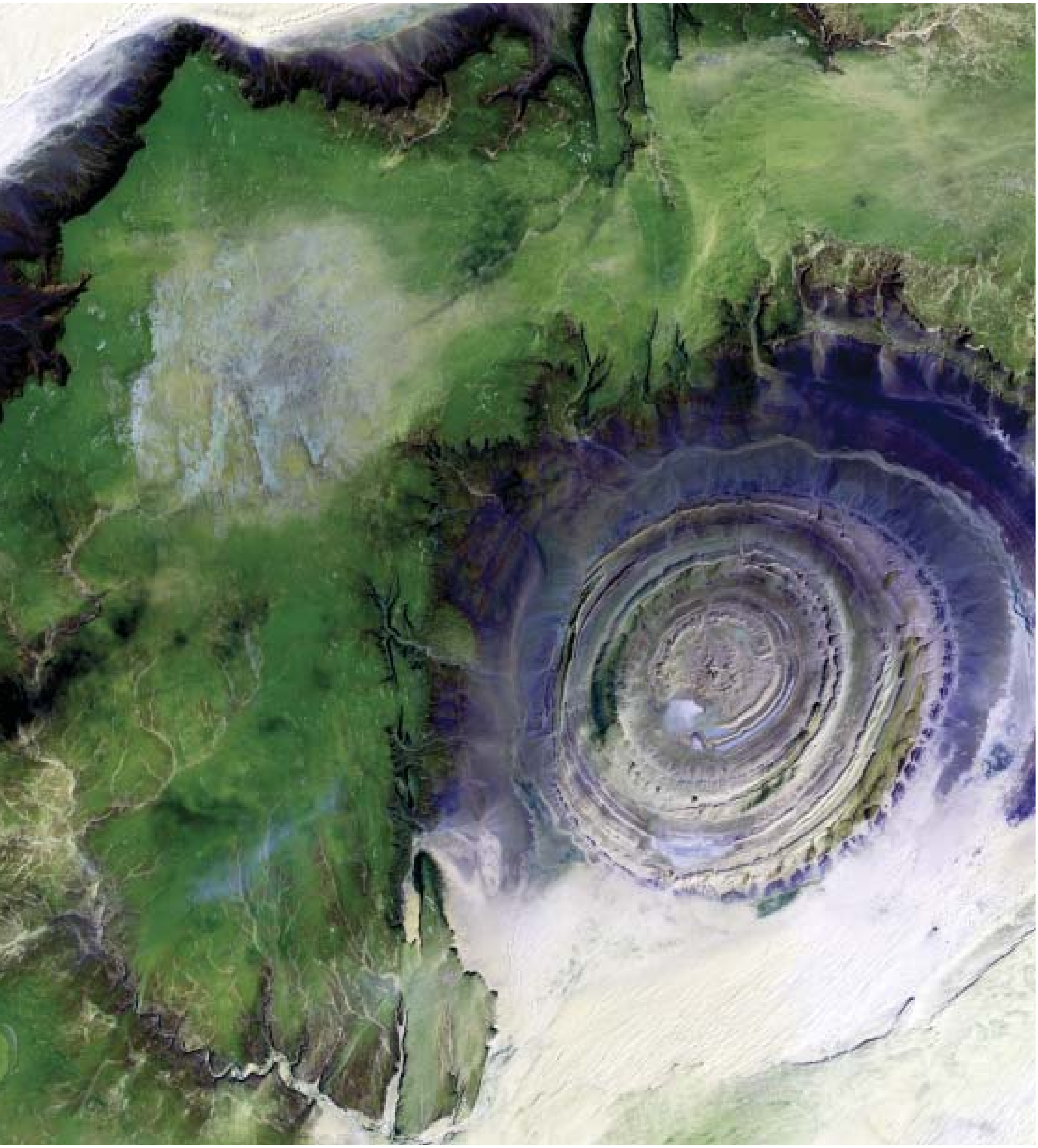
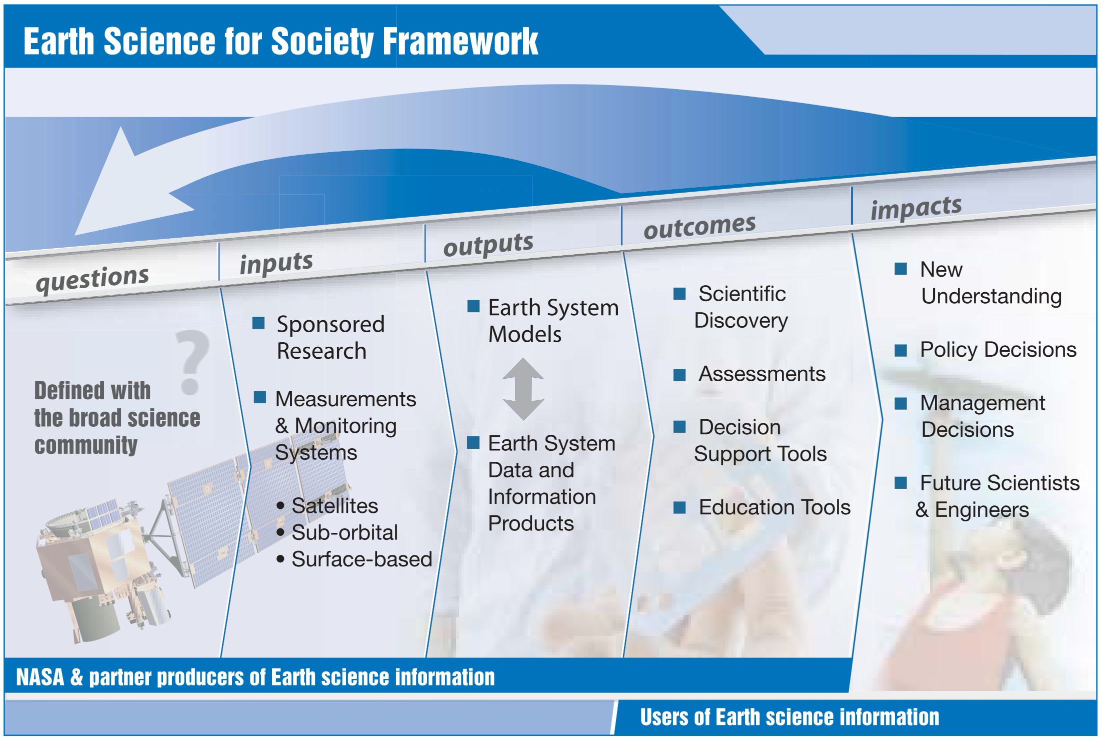


Figure 2.3



2.3 Strategic Framework

Earth system science is related to many important issues of societal concern. The Earth Science Enterprise has therefore adopted a science-driven and results-oriented planning and implementation framework. The continuum from science to applications will be traversed through a logical progression of observation, research and data analysis, modeling, and scientific assessment. Our goal is to leverage our capabilities into valuable decision support for our Nation's policymakers, government services, businesses, and citizens. NASA is teaming with its university, Federal agency, and industry partners to benchmark Earth system science applications that will benefit society, as shown in figure 2.3.

Essential Components of the Earth Science Enterprise Framework

Research.—Consult with Earth science community, partner agencies, and the National Research Council to identify and prioritize science questions and establish goals; develop 10-year plan for observation and research needed to achieve goals; facilitate research to define requirements for observing systems, analyze resulting observations, develop process models, conduct scientific assessments of global change

Observation and Information Systems.—Design and implement an integrated observing strategy with our partners that encompasses satellite, suborbital and surface-based platforms; determine observations requirements and information systems needed for stewardship of the resulting data and knowledge products.

Advanced Technology.—Create and adapt new remote sensing, computing, and communications technologies to enable Earth system research and applications

Applications.—Work with partner agencies to improve decision support tools that utilize NASA's Earth science observations and research results to provide essential services to the Nation

Education.—Make NASA knowledge more readily available to the education community; assist educators in creating tools and approaches for teaching Earth system science

2.4 Partnerships

NASA's Earth Science Enterprise has many partners in the advancement of Earth system science and its application to societal concerns. Enterprise partnerships include:

- Federal agencies affiliated with the U.S. Climate Change Science and Technology Programs; to provide a sound scientific basis for the policy decisions and to mitigate or adapt to the impacts of climate change

- Other Federal agencies that use NASA research and information; to improve the delivery of the essential services these agencies provide to the Nation

- Private industry; to develop technologies of the future; specific involvement with the commercial remote sensing industry to enhance the scientific utility of commercial imagery

- 290 agreements with 60 countries; NASA is a leading contributor to international research programs and scientific assessments of environmental change, as well as efforts by the world's space agencies to design and deploy a comprehensive and coordinated global observing system

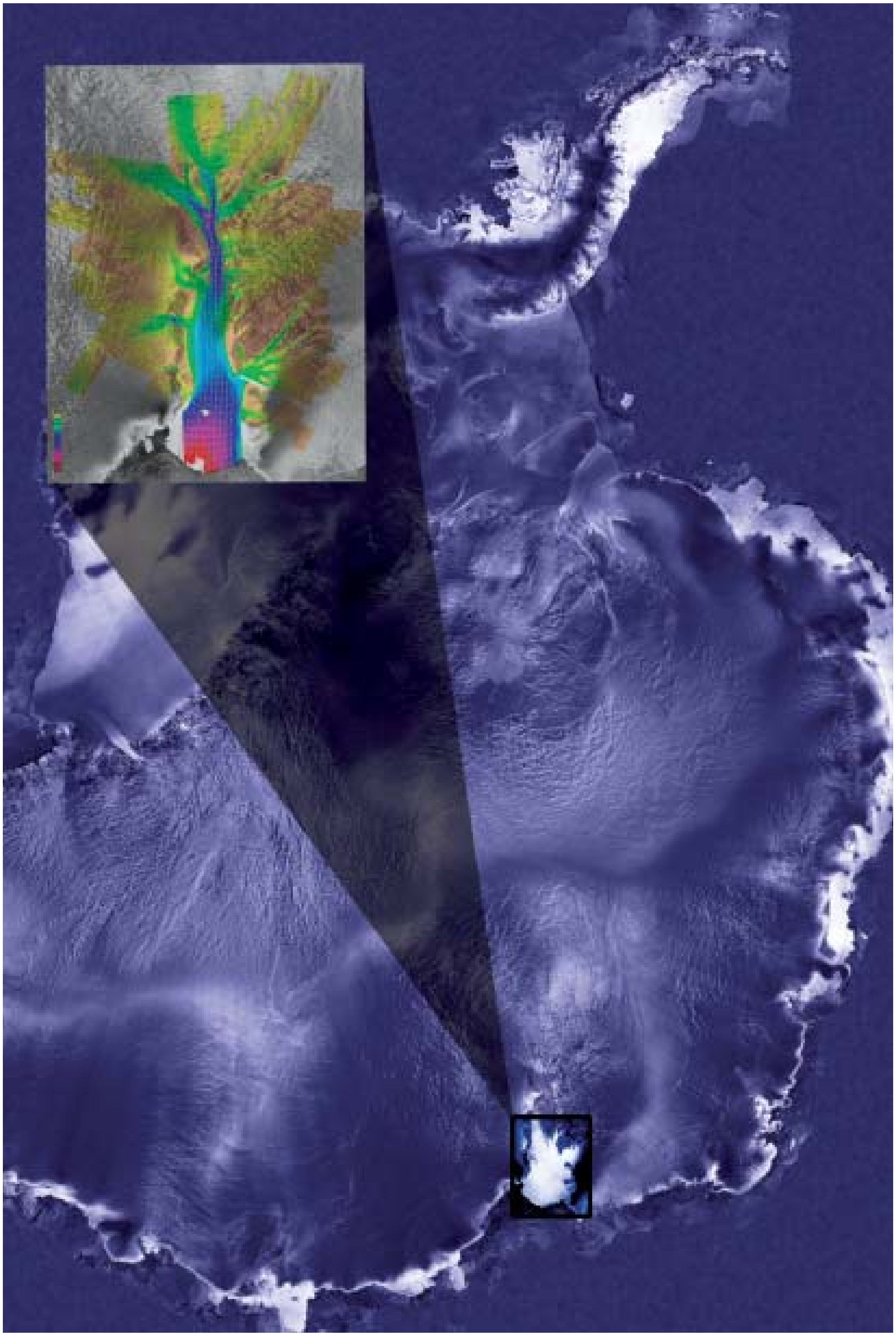
- Nearly 2000 research and technology grants and contracts with universities and research laboratories nationwide for basic research, benchmarking applications of new scientific results, and creating innovative technologies

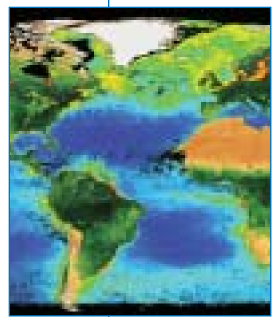
These partnerships are described further in section 4 (Strategy Implementation).

NASA and NOAA Watch Weather from Space

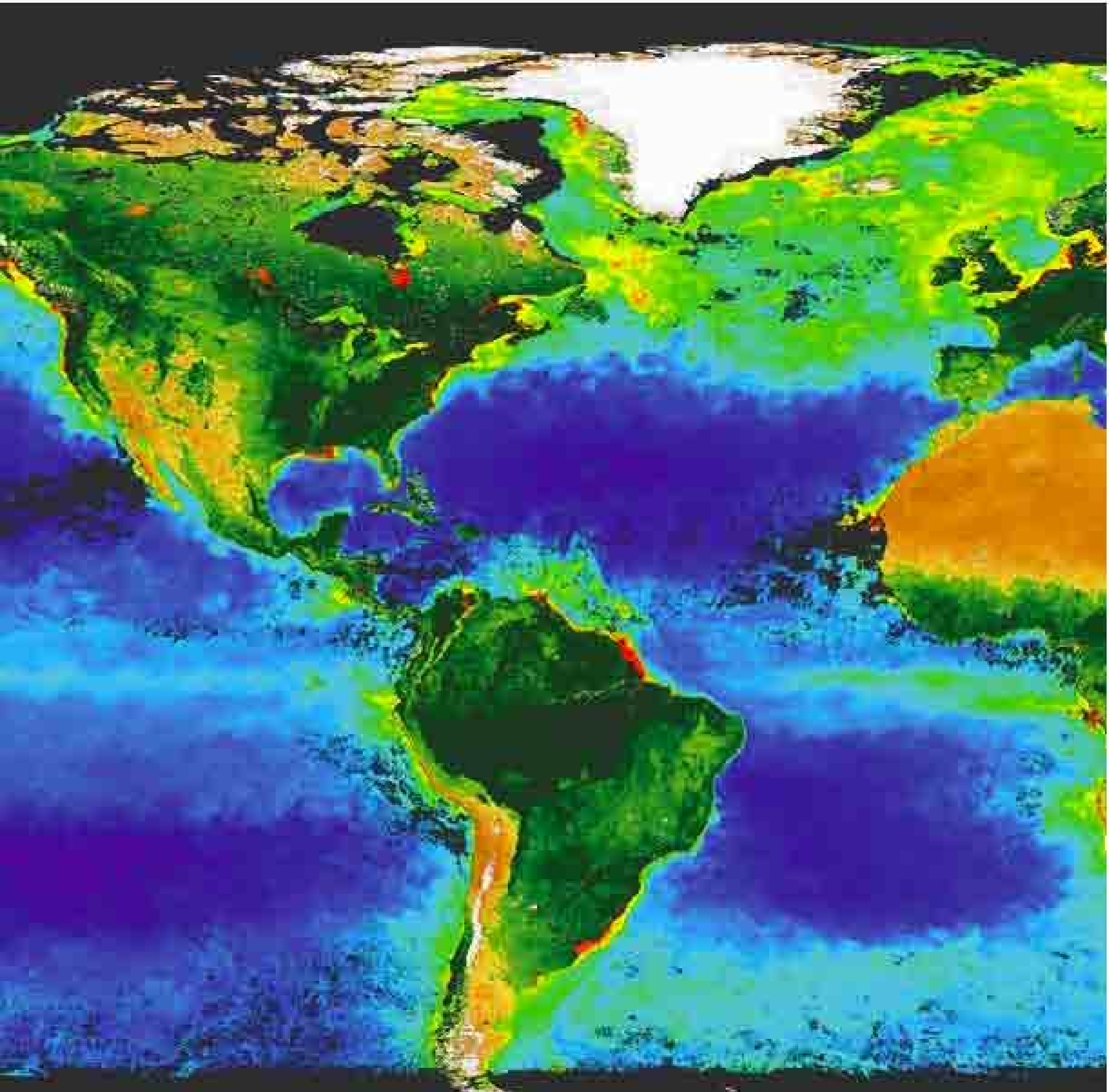
In April 1960, NASA launched the first Television Infrared Observation Satellite (TIROS) to test experimental television techniques designed to develop a worldwide meteorological satellite information system. NASA continues to design, develop and launch the Nation's civilian operational environmental satellites, in both polar and geostationary orbits, by agreement with the National Oceanic and Atmospheric Administration (NOAA). NOAA assumes control of these satellites after activation, and provides the resulting data on a continuous basis for weather prediction and other services. NASA's Earth Observing System (EOS), in addition to enabling global change research with advanced sensors, serves as the technology source for the next generation of Polar-Orbiting Operational Environmental Satellites (POES). NOAA, DOD, and NASA are proceeding with the development of POES in a joint civilian/military project called NPOESS. Bridging EOS and NPOESS is the NPOESS Preparatory Project (NPP or "Bridge Mission"), a multi-instrument satellite that will extend climate change measurements begun by EOS Terra and Aqua while demonstrating new technologies for NPOESS. NASA and NOAA also continue to plan the next generation of Geostationary Operational Environmental Satellites (GOES). NASA plans to fly an advanced atmospheric sounder to a geostationary orbit where it will make continuous measurements of weather-related phenomena to improve "nowcasting" of extreme weather events and measurement of important atmospheric gases. Today's satellites have enabled weather forecasts to be extended from three days to five. The next generation of satellites will enable the extension of forecasts to seven days within this decade.

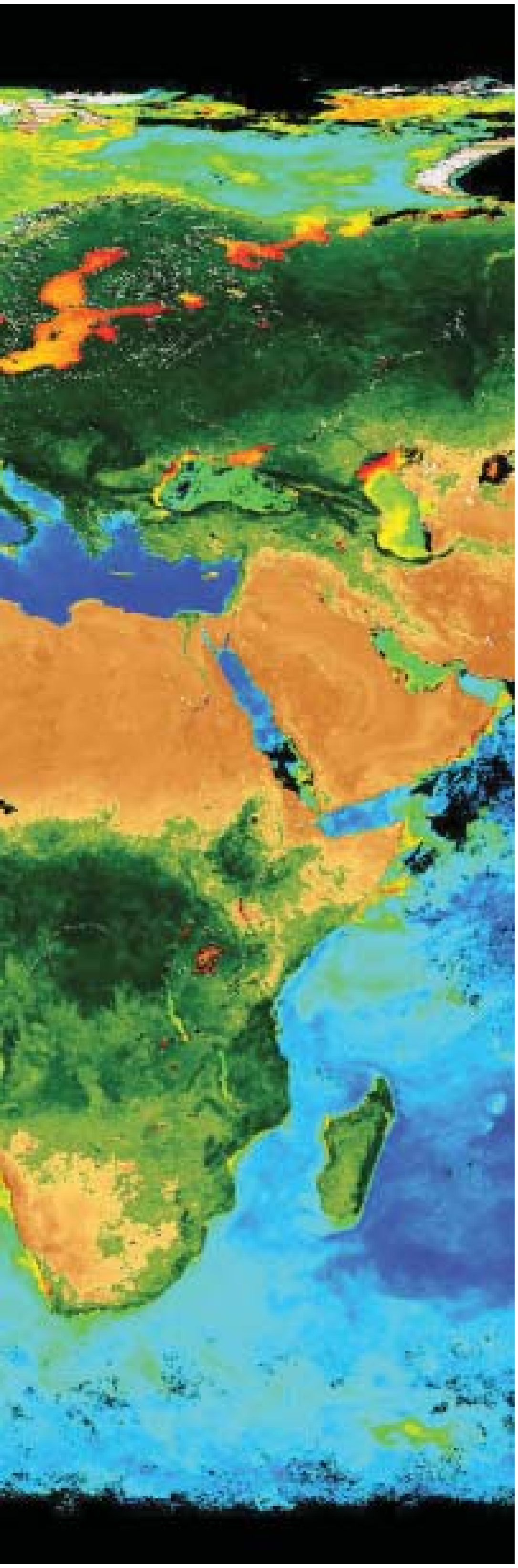
Shown at right: Two successive Antarctic Mapping Missions using the joint Canada/U.S. Radarsat 1 satellite yielded the first detailed radar maps of the Antarctic ice sheet, and revealed rates of change as ice moves from the interior to the oceans. The Lambert Glacier is one such ice floe. By the time ice from the interior reaches the sea, it is moving at 1 kilometer per year.





3 Achieving NASA's Earth Science Objectives





3 Achieving NASA's Earth Science Objectives

The NASA Strategic Plan is based on a hierarchy of the Agency's Vision, Mission, goals, themes and objectives (figure 3.1). The Vision and Mission are guiding principles for NASA and articulate NASA's fundamental contribution to the Nation and the world. To carry them out, the Agency has established goals that outline what we will achieve in the coming decade and beyond. They provide the context for program selection, planning and development. To meet each goal, the Agency has established a set of objectives to be achieved by the six Enterprises. The Enterprises develop performance plans and reports against those objectives. Budgetary resources to accomplish those objectives are allocated to the Enterprises in budget themes. Resources and performance for each theme and its objectives are documented in the Integrated Budget and Performance Document published each year as a companion to the NASA Strategic Plan. The NASA Strategic Plan also identifies a set of implementing strategies to be employed across the Agency for effective management of its programs. Various non-Enterprise "functional" offices, who lead the implementing strategies, are identified in the NASA Strategic Management Handbook.

The Sea-viewing Wide Field-of-View Sensor (SeaWiFS), aboard Orbital Sciences Corporation's OrbView-2 satellite, has given researchers an unprecedented view of the biological engine that drives life on Earth—the countless forms of plants that cover the land and fill the oceans. SeaWiFS data, based on continuous daily global observations, have helped scientists make a more accurate assessment of the oceans' role in the global carbon cycle. The image above, created by scientists at NASA's Goddard Space Flight Center, shows the global biosphere from June 2002 measured by SeaWiFS. Data in the oceans is chlorophyll concentration, a measure of the amount of phytoplankton (microscopic plants) living in the ocean. On land SeaWiFS measures the Normalized Difference Vegetation Index, an indication of the density of plant growth.

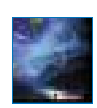


Figure 3.1

This section of the Strategy describes what the Earth Science Enterprise will do to accomplish NASA's goals and objectives. Table 3.1 lists the goals and objectives to which the Earth Science Enterprise contributes, either in whole or in part. The balance of this section more fully describes our work toward these objectives, as organized by the Enterprise's two themes: Earth System Science and Earth Science Applications.

NASA's goal in Earth science is to observe, understand, and model the Earth system to discover how it is changing, to better predict change, and to understand the consequences for life on Earth. We do so by characterizing, understanding, and predicting change in major Earth system processes and by linking our models of these processes together in an increasingly integrated way.

Figure 3.2 portrays the basic science for society framework, with the major enabling elements required to achieve the Enterprise objectives shown on the perimeter. The sections that follow discuss our strategic approach to each of the major program elements—Research, Observation and Information Management, Applications, Advanced Technology, and Education. Within the NASA budget and planning (theme) structure, the Research, Observation and Information Management, and Advanced Technology programs are grouped into the Earth System Science theme, while the Applications and Education programs are grouped into the Earth Science Applications theme.

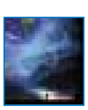


Table 3.1

Earth Science Enterprise Contributions to NASA Goals and Objectives

NASA Goal	NASA Objective	NASA Budget Theme	Earth Science Enterprise Contribution
1. Understand the Earth system and apply Earth system science to improve the prediction of climate, weather, and natural hazards	1.1: Understand how Earth is changing; better predict change and understand the consequences for life on Earth	Earth System Science	This is core of the Enterprise mission; while the Enterprise pursues other initiatives, they stem from our primary research on the interaction of land, atmosphere, oceans, ice, and life on the planet.
	1.2: Expand and accelerate the realization of economic and societal benefits from Earth science, information, and technology	Earth Science Applications	As a Federal agency whose research bears directly on areas of substantial societal concern, the Enterprise is obligated and privileged to make its research findings available to those providing essential public services.
	1.3: Understand the origins and societal impact of variability in the Sun-Earth connection	Earth System Science	Study the effects of solar variability on the Earth, in conjunction with Sun-Earth initiatives facilitated by the Space Science Enterprise
2. Enable a safer, more secure, efficient, and environmentally friendly air transportation system	2.1: Decrease the aircraft fatal accident rate 2.2: Protect local and global environmental quality by reducing aircraft noise and emissions	Earth Science Applications	Support the Aerospace Technology Enterprise (AT) through advanced weather prediction, the detection of volcanic activity, and measurement of topography in remote areas. Work with the AT to study the atmospheric effects of aviation and improve the compatibility of aviation with the environment.
3. Create a more secure world and improve the quality of life	3.2: Improve the Nation's economic strength and quality of life by facilitating the innovative use of NASA technology	Earth Science Applications	Contribute to public safety and national security by improving climate, weather and natural hazard forecasting and providing measurements of land cover, topography, oceans, and atmospheric properties.
5. Explore the solar system and the universe beyond	5.1: Learn how the solar system originated and evolved to its current diverse state	Earth System Science	As the only known planet with life, Earth serves as a paradigm for studying other planets and their moons and searching for life-compatible conditions.
6. Inspire and motivate students to pursue careers in science, technology, engineering and mathematics	6.1–6.4: Increase the number of students and teachers involved in NASA-related education opportunities	Earth Science Applications	Enable and extend the use of Earth system science content to enrich STEM and geography education.
7. Engage the public in shaping and sharing the experience of exploration and discovery	7.1: Improve public understanding and appreciation of science and technology	Earth Science Applications	Collaborate with science centers, museums and other informal learning institutions to incorporate Earth system science concepts and materials.

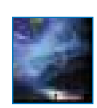
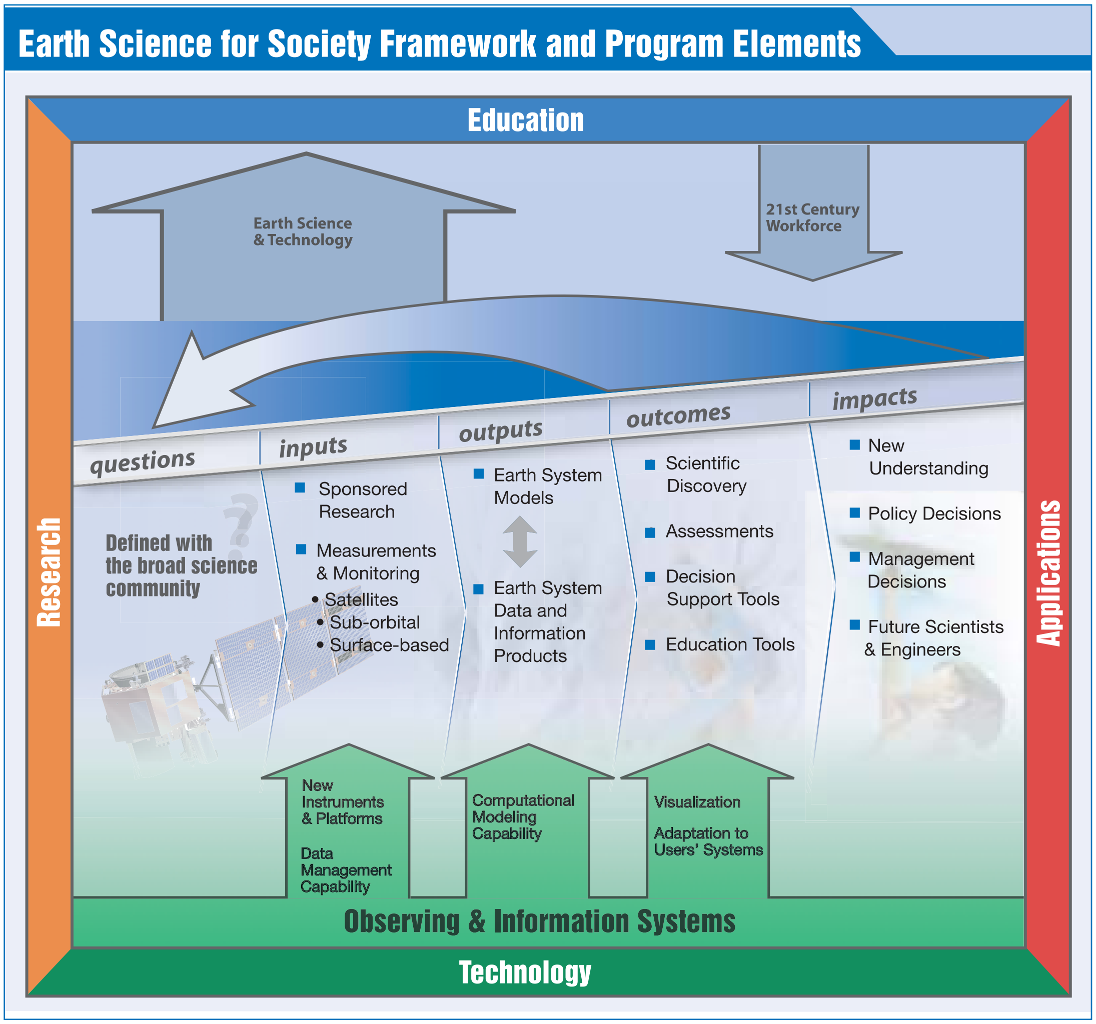


Figure 3.2



3.1 Earth System Science Theme

NASA's Earth System Science theme comprises the Enterprise's Research, Observation and Information Management, and Advanced Technology programs.

3.1.1 Research Program

The frontier of Earth system science is to: (1) explore interactions among the major components of the Earth system—continents, oceans, atmosphere, ice, and life, (2) to distinguish natural from human-induced causes of change, and (3) to understand and predict the consequences of change. We have established six scientific focus areas for these complex processes, along with applications for each focus area.

In each of these areas, the Earth Science Enterprise seeks the input of the Earth science community in universities and elsewhere to identify the scientific questions to be addressed and to define effective strategies to pursue the answers to those questions. The Enterprise chartered the Solid Earth Science Working Group, led by a member of our external science advisory committee and comprising experts from around the Nation, to layout a course of research for the next two decades. The report of this group was the starting point for the Earth Surface and Interior science focus area roadmap (summarized on pages 42-43). Similarly, we have utilized interagency carbon cycle and water cycle research planning in defining NASA's future contributions in these science focus areas. The U.S. Weather Research Program's priorities are the basis for planning in our Weather science focus area.

The next challenge, as illustrated in figure 3.3, is to further integrate these six focus areas into a comprehensive understanding of the Earth system, represented by process models and coupled models. The Enterprise will develop these models around scientific prediction questions for each focus area. This is shown in table 3.2, along with projected outcomes from research and development over the next 10 years.

The Earth Science Enterprise Research Strategy (available online at *http://earth.nasa.gov/visions/researchstrat*) discusses our approach to answering the prediction questions at greater length. Appendix 4 lists the specific questions underlying the prediction questions. The following strategic principles govern the formulation and implementation of the Research program of the Earth Science Enterprise:

- Choose scientific questions for which NASA technology and remote sensing can make a defining contribution
- Pursue answers to these questions using an "end-to-end" systems approach that includes observation, research and data analysis, modeling, and scientific assessment in collaboration with our partners
- Engage the broader Earth science community throughout the process, from question formulation to the final release of findings to decisionmakers and the public
- Identify and generate a specific set of validated climate data records in collaboration with the science community and our domestic and international partners
- Create data assimilation capabilities for available diverse data types

Figure 3.3

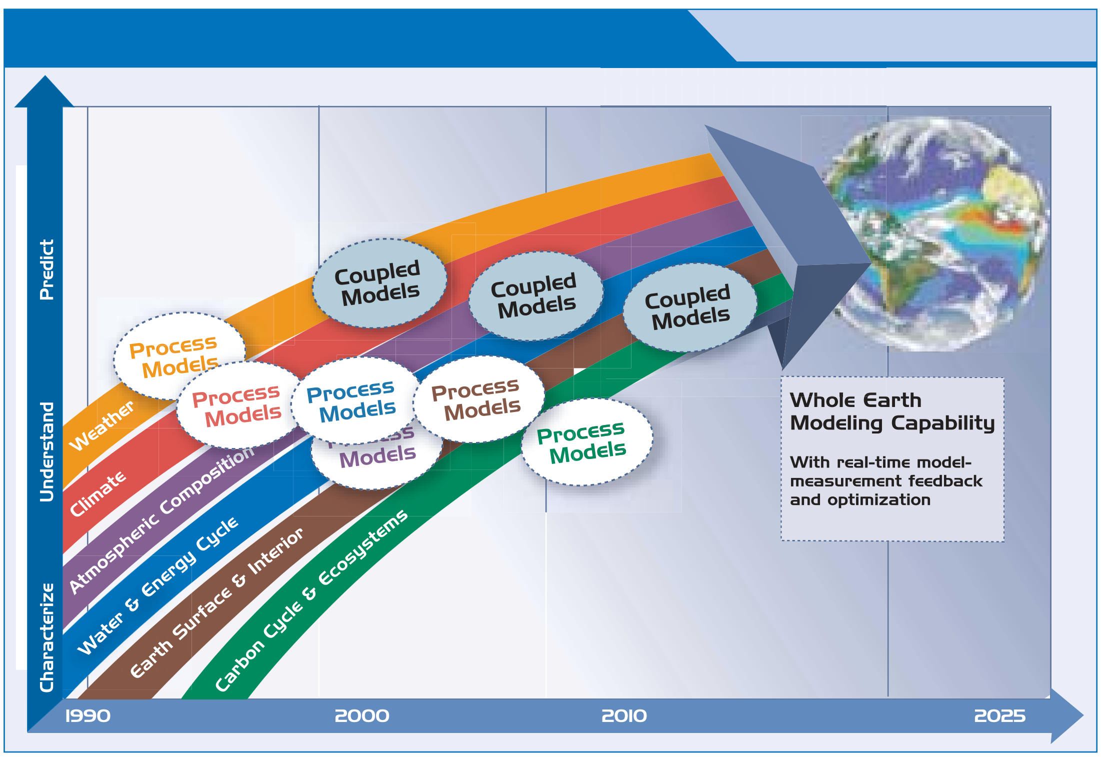
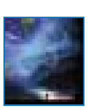
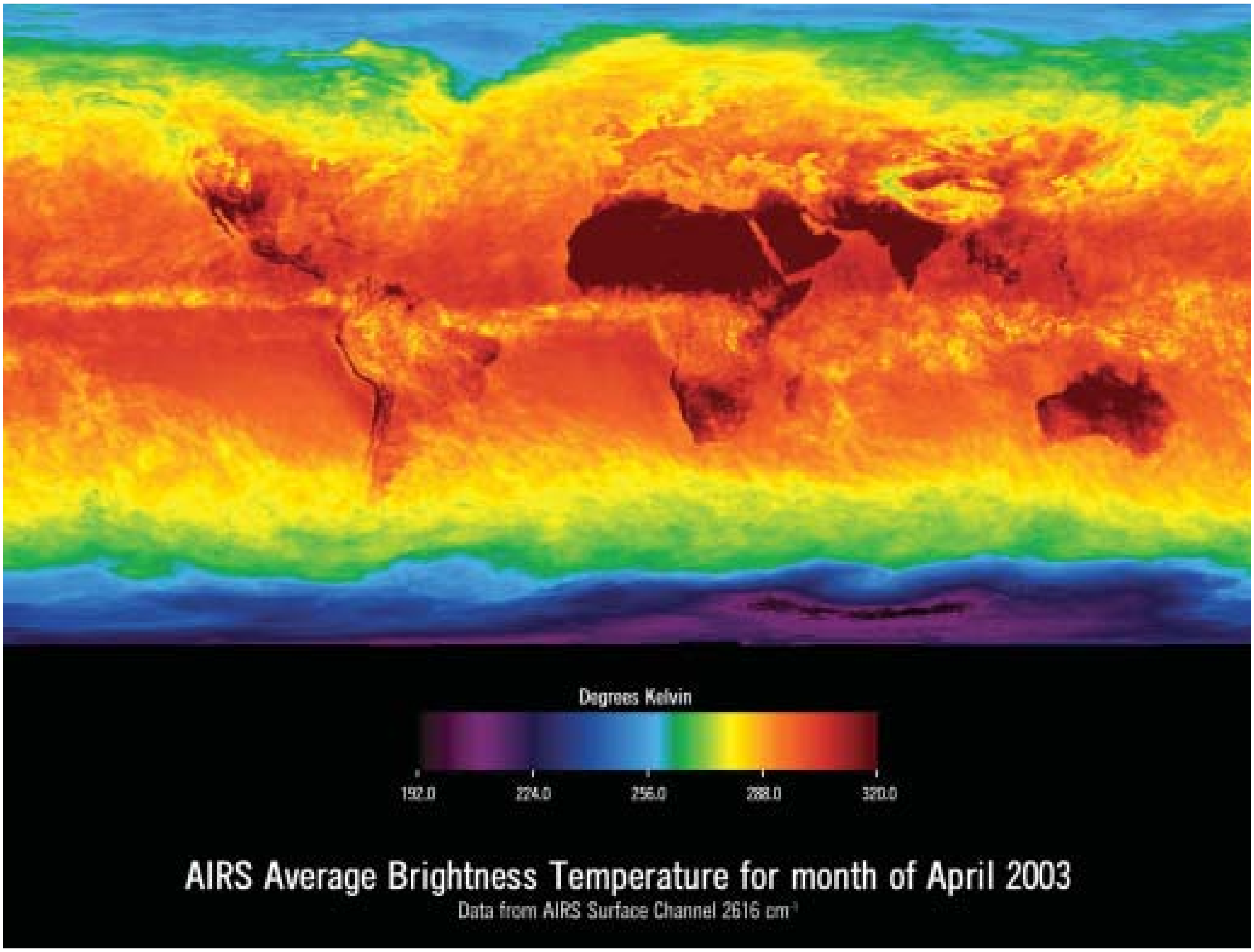


Table 3.2

Science for Society: Projected Outcomes from NASA Earth System Science

Science Focus Area	Prediction Question	10-Year Outcomes (With Partners)
Climate Variability and Change	How can predictions of climate variability and change be improved?	Predict near and long-term climate change, implications for global sea level change, regional temperature, precipitation, and soil moisture; e.g.: • reduce uncertainty in global sea level rise by 50 percent by 2014 • enable 10-year or longer climate forecasts by 2014
Atmospheric Composition	How will future changes in atmospheric composition affect ozone, climate, and air quality?	Predict the course of recovery of Earth's atmospheric ozone shield and assess the quality of the air we breathe; e.g.: • predict global distribution of stratospheric and tropospheric ozone to within 25 percent by 2014 • enable extension of air quality forecasts for ozone and aerosols from 24 to 72 hours by 2014
Carbon Cycle, Ecosystems, and Biogeochemistry	How will carbon cycle dynamics and terrestrial and marine ecosystems change in the future?	Predict global terrestrial and ocean biological productivity, ecosystem health, and interactions with the climate system, e.g.: • project 10 to 100-year concentrations of carbon dioxide and methane with greater than 50 percent improvement in confidence by 2014 • enable ecological forecasts that project sensitivity of terrestrial and marine ecosystems by 2014
Water and Energy Cycle	How will water and energy cycle dynamics change in the future?	Improve intermediate range forecasts for droughts and seasonal water supply; predict global scale energy storage and transport in the atmosphere, e.g.: • enable seasonal precipitation forecasts with greater than 75 percent accuracy at 10s of km resolution by 2014 • balance global water and energy budgets to within 10 percent by 2014
Weather	How can weather forecast duration and reliability be improved?	Significantly improve short-term and severe weather forecasting capabilities for hurricanes, winter storm hazards, and extreme weather events, e.g.: • enable decreased hurricane landfall uncertainty from plus/ minus 400km to plus/minus 100 km in 3-day forecasts by 2014 • enable 7-10 day forecasts at 75 percent accuracy by 2014
Earth Surface and Interior	How can our knowledge of Earth surface change be used to predict and mitigate natural hazards?	Predict volcanic activity within a month and estimate earthquake probabilities for selected tectonic zones, e.g.: • enable 30-day volcanic eruption forecasts with greater than 50 percent confidence by 2014 • enable estimation of earthquake likelihood in North American plate boundaries with greater than 50 percent confidence by 2014





- Develop computational modeling capabilities for research focus areas, for example:

(1) Acquire the computing capacity to enable robust operation of Earth system models as they become more complete and complex

(2) Assimilate new satellite, suborbital, and in situ observations into Earth system models

(3) Lead a consortium of agencies and universities to establish a common modeling framework of standards and protocols that will allow diverse institutions to collaborate on complex Earth system modeling endeavors

(4) Work with industry in the development of new computation, networking, data storage, and data access capabilities to link models and assimilate observational data from diverse institutions to meet growing computational modeling requirements

(5) Develop Earth system models that incorporate observations, together with process modeling, to simulate linkages between the processes studied in the research focus areas, e.g.: (a) coupling between atmospheric composition, aerosol loading, and climate; (b) coupling between aerosol processes and the hydrological cycle, and (c) coupling between climate variability and weather

The atmospheric infrared sounder on the Aqua satellite will lead to the next generation of weather forecasting capabilities.

- Participate in national and international scientific assessments of the state and directions of Earth system change in support of policy and economic decision-making processes; we align our science priorities with those of major national imperatives, such as the following:

(1) Reduce uncertainties in our understanding of the causes and consequences of global change (U.S. Climate Change Science Program), and enable options for mitigation and adaptation (U.S. Climate Change Technology Program)

(2) Improve duration and reliability of weather forecasts (U.S. Weather Research Program)

(3) Reduce vulnerability to natural and human-induced disasters subcommittee on Disaster Reduction)

(4) Understand and predict changes in the world's oceans (National Ocean Partnership Program (NOPP))

(5) Understand global change signals from and impacts on polar regions (Study of Environ-mental Arctic Change (SEARCH))

- Establish and maintain critical linkages to the Space Science Enterprise in areas such as the Sun-Earth Connection theme, Living with a Star program, astrobiology, and comparative planetology.

As figure 3.2 indicates, the six science focus areas are interrelated, and must eventually be integrated to arrive at a fully interactive and realistic Earth system representation. For each science focus area, the Enterprise has developed a decadal roadmap guiding Enterprise investments and describing how we intend to achieve the outcomes listed above. These roadmaps are summarized at the highest level here. The roadmap summaries beginning on the next page show the science products being produced today and those we believe we can deliver, or enable others to deliver, 10 years from now. In between, we show the knowledge progress steps required to get there, and the observation and modeling capabilities we must create to acquire that knowledge. The pages to follow provide a summary-level view of the roadmap to predictive capability in each science focus area. Fully detailed roadmaps for each science focus area can be accessed at the *earth.nasa.gov* Web site.

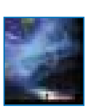
Earth System Modeling Framework

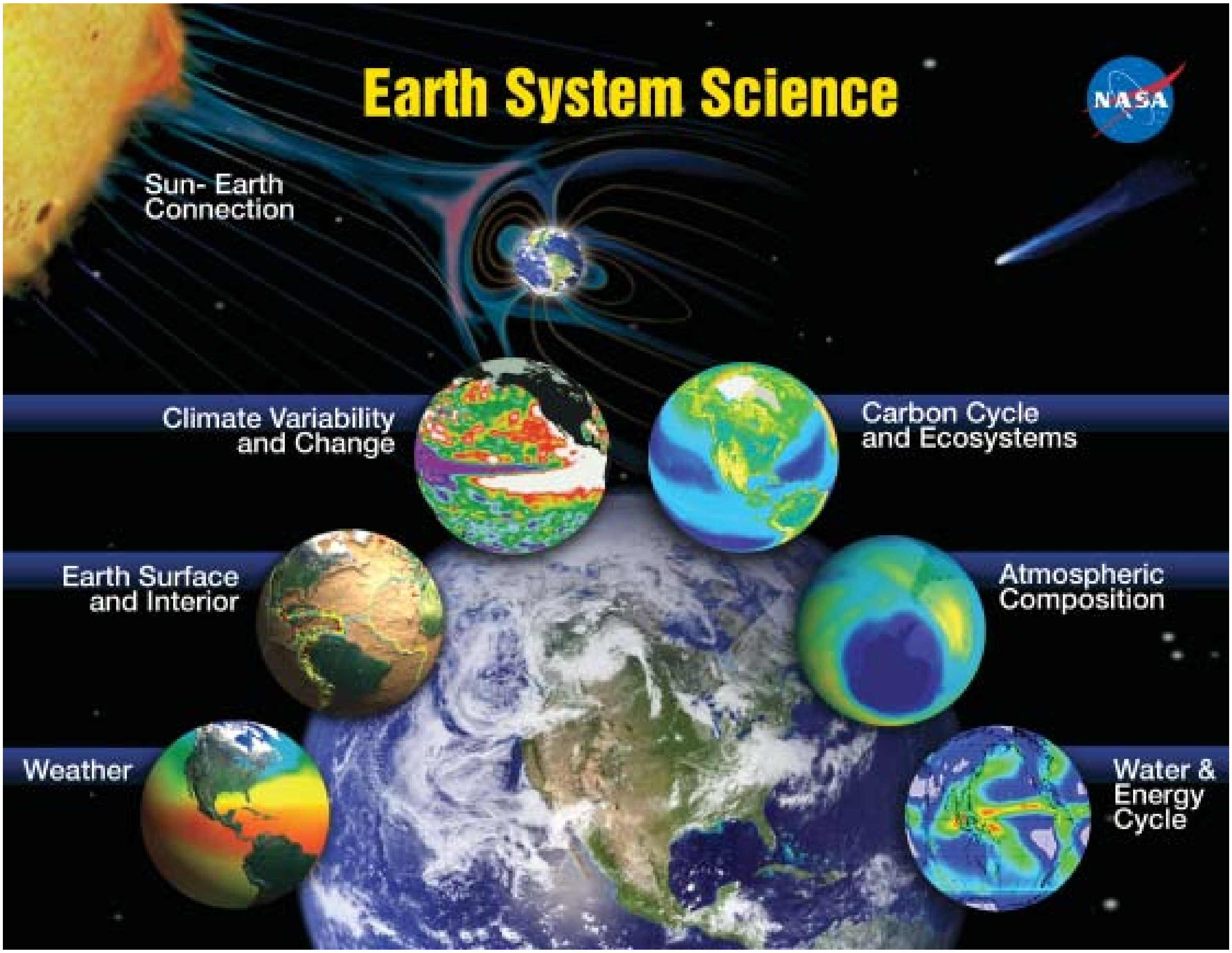
Over the last few years, the need for software infrastructure for Earth system modeling has grown increasingly apparent. Models and the computational platforms that they run on have become extremely complex, leading to excessive time and resources dedicated to solving computational rather than scientific problems. To tackle these challenges, NASA initiated a partnership with NSF, NOAA, DOE and over a dozen universities.

The Earth System Modeling Framework (ESMF) collaboration, which consists of Earth scientists and computational experts from major U.S. Earth modeling centers, is developing a robust, flexible set of software tools to enhance ease of use, performance portability, interoperability, and reuse in climate, numerical weather prediction, and data assimilation applications. The ESMF will allow diverse scientific groups to leverage common software to solve routine computational problems such as efficient data communication, model component coupling and sequencing, time management, and parameter specification. In an open dialogue with the broader community, our collaboration will also develop a software interface specification so that groups working at different institutions and in different disciplines can generate interoperable software components.

Past Climate Change

A complete assessment of the causes and consequences of past climate change cannot be made with modern data alone. Past climate changes and their impacts on human civilization must be understood, through such means as examination of air bubbles in ice cores extracted from polar ice sheets. The National Science Foundation is the lead agency for research on past climate change, termed "paleoclimateology" for the U.S. Climate Change Science Program. Researchers combine these data from past eras with those from modern sensing and sampling techniques to piece together climate records that show modern changes in their historical context.

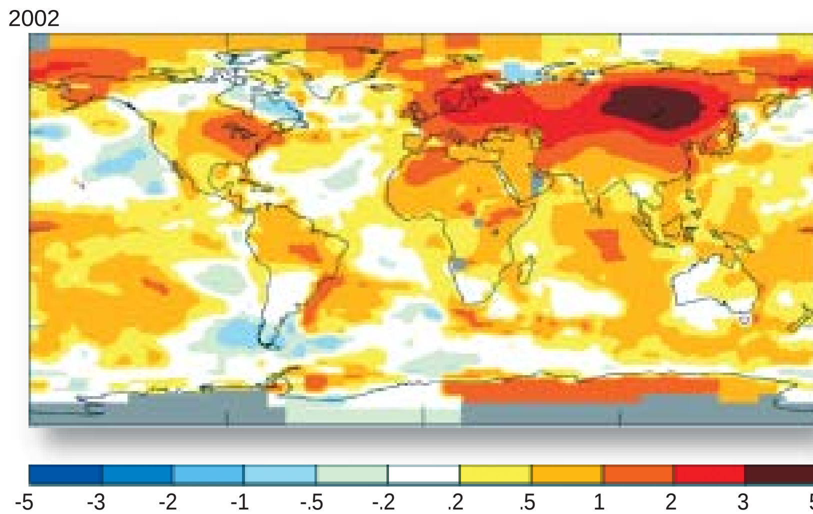



Earth System Science
NASA
Sun- Earth Connection
Climate Variability and Change
Carbon Cycle and Ecosystems
Earth Surface and Interior
Atmospheric Composition
Weather
Water & Energy Cycle

How Can Predictions of Climate Variability and Change Be Improved?

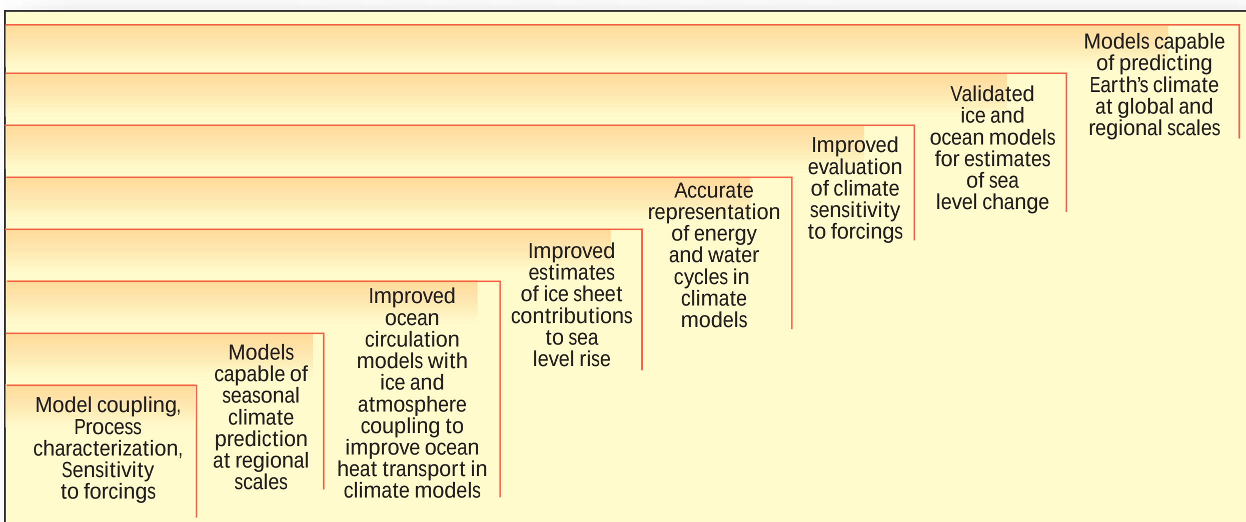
TODAY'S PRODUCTS

- Experimental forecasts of surface temperature and precipitation
- Fair knowledge of global climate variables and their trends
- Climate models that simulate long-term global temperature change with large uncertainty in forcings and sensitivity



Surface Temperature Anomaly (°C)
January through September

KNOWLEDGE STEPS



2003 → 2014

From Global Climate...

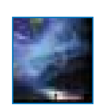
REQUIRED CAPABILITIES

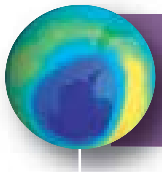
	Current/Planned	Future
Observations		
Sun	Solar irradiance from ACRIM, SORCE	Continuity via research & operational satellites
Atmosphere	Temperature & humidity via Aqua, NPP-Bridge; Cloud properties via Terra, Cloudsat Aerosols via Terra, Calipso, Glory Greenhouse gases via Aura, SAGE, Orbiting Carbon Observatory Precipitation via Global Precipitation Measurement	Atmospheric data continuity via research & operational satellites Global atmospheric aerosols via future chemistry/climate mission(s) Greenhouse gases via future chemistry/climate mission(s)
Oceans	Sea surface temperature via Aqua, NPP-Bridge Ocean topography via Jason, Ocean Surface Topography Mission Ocean winds via SeaWinds, Coriolis, Ocean Vector Winds Mission Sea surface salinity via Aquarius	Data continuity via research and operational satellites Deep ocean circulation mission
Ice	Sea ice extent via Aqua Ice sheet mass balance via ICEsat, GRACE	Data continuity/revisits via follow-on research missions; Interferometric Synthetic Aperture Radar
Land	CO_2 sources & sinks via MODIS, Landsat, NPP-Bridge Mission	Soil moisture mission, Terrestrial ecosystem mission
Computational Modeling	Coarse resolution global modeling, assimilation of key new data types	10^4 times today's capability for modeling at regional resolutions and assimilation of active remote sensing data

10 YEAR OUTCOME

- Reduce uncertainty in global sea level rise projections by 50% by the year 2014, and include regional estimates of deviation from global mean.
- Enable 10-year or longer climate forecasts by the year of 2014 with a national climate modeling framework capable of supporting policy decision making at regional level.

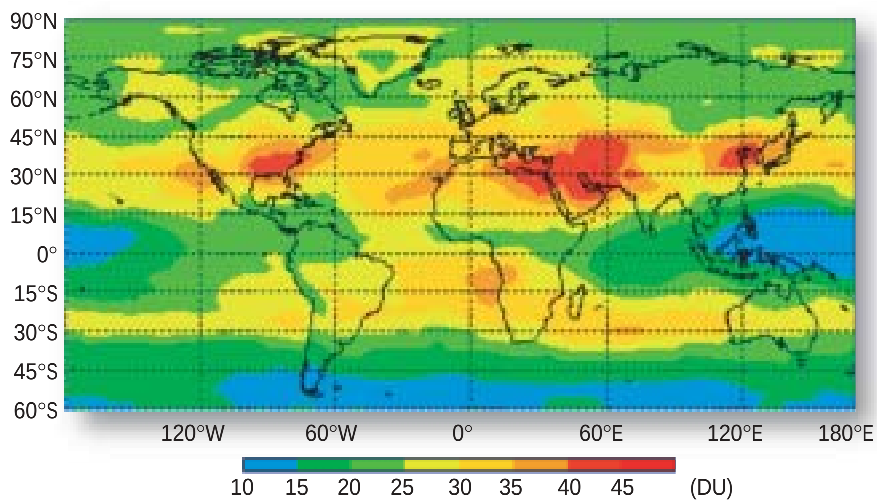
TO PREDICTION OF REGIONAL IMPACTS



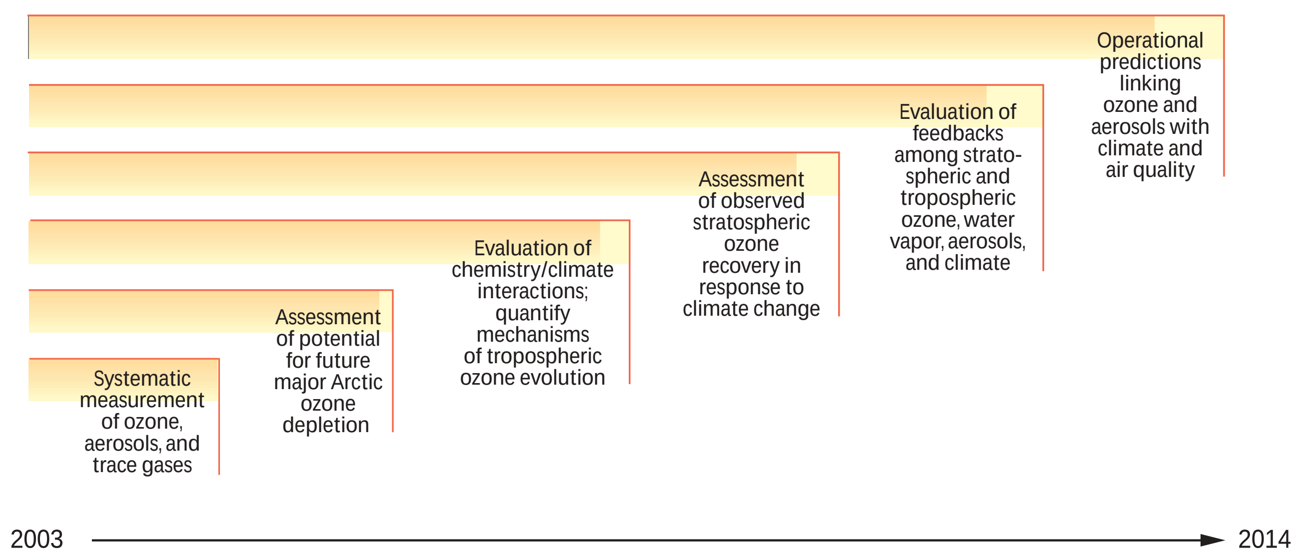


How Will Future Changes in Atmospheric Composition Affect Ozone & Climate?

- Over two decades of global ozone data; monitoring concentrations of ozone depleting substances following treaty implementation
- Limited observations of global distributions of tropospheric pollutants
- Projections (with high uncertainty) of climate change impacts on ozone recovery



Global model simulation of tropospheric ozone columns



Understanding Earth's Atmosphere…

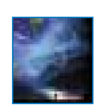
REQUIRED CAPABILITIES

	Current/Planned	*Future*
Observations		
Stratospheric Chemistry	Systematic measurement of stratospheric ozone, trace gases and water vapor via TOMS, Aura, NPP-Bridge	Data continuity via research and operational satellites, atmospheric chemistry mission
Tropospheric Chemistry	Exploratory measurement of tropospheric ozone and its precursors via Aura, suborbital systems	Systematic measurement of tropospheric chemistry, regional pollution tracking
Aerosols	Aerosol measurement via MODIS, MISR, SAGE, Calipso, Glory	Data continuity via research and operational satellites, aerosol measuring mission
Computational Modeling	Global modeling initiative Chemical transport models	Capacity for 1 km vertical, 1° x 1° horizontal resolution Coupled climate - chemistry - aerosol models

10 YEAR OUTCOME

- Enable prediction of polar and global stratospheric ozone recovery (amount and timing) to within 25% by 2014.
- Predict the global distribution of tropospheric ozone and the background concentration in continental near-surface air to within 25% by 2014.
- Enable extension of air quality forecasts for ozone and aerosols from 24 to 72 hours by 2010.

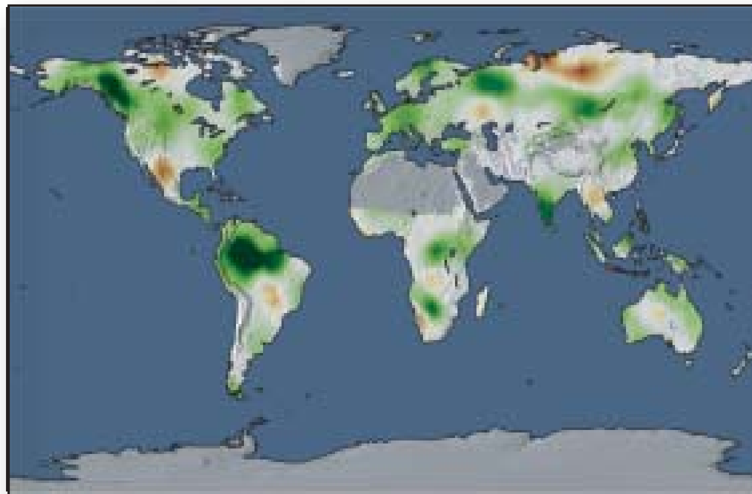
TO PROTECT THE AIR THAT SUSTAINS US



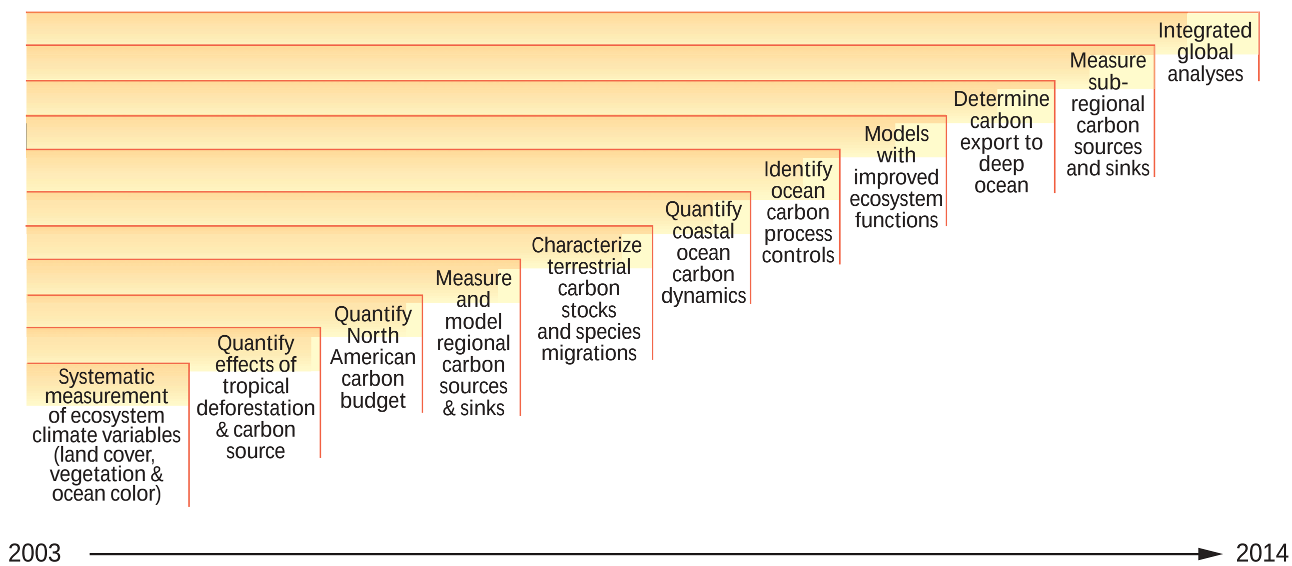
How Will Carbon Cycle Dynamics and Terrestrial & Marine Ecosystems Change in the Future?

- Global land cover at coarse resolution and primary productivity of terrestrial and marine ecosystems
- Models of atmosphere/biosphere exchange of carbon dioxide and methane
- Documentation of large uncertainties in biomass, fluxes, effects of disturbance, and knowledge of processes in the coastal zone

Change in Terrestrial NPP from 1982 to 1999.



Nemani et al., Science June 6th 2003



Life in the Earth System…

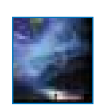
REQUIRED CAPABILITIES

	Current/Planned	Future
Observations		
Oceans	Systematic measurement of global ocean color via SeaWiFS, Terra, Aqua, NPP-Bridge	Data continuity via commercial partnerships, research and operational satellites Carbon stocks in the Southern Ocean via Southern Ocean Carbon Program Profiles of ocean particles via lidar
Carbon Cycle	Carbon stocks in North America via North American Carbon Program Regional terrestrial carbon stocks and structure via airborne lidar Global atmospheric CO_2 column for determination of sources and sinks via Aqua and Orbiting Carbon Observatory	High-resolution atmospheric CO_2 via laser sounder Global methane, wetlands and flooding via fusion of multiple existing and new data types
Terrestrial Ecosystems & Land Cover	Systematic measurement of global land cover and use via Terra, Aqua, Landsat and commercial sensors	Data continuity via commercial partnerships, research and operational satellites Global vegetation physiology and functional groups via hyperspectral imager Global vegetation 3-D structure, biomass & disturbance via lidar, radar, and/or hyperspectral radiometry
Computational Modeling	Beginning stages of ecosystem modeling; assimilation of key new data types	10^4 times today's capability for modeling at regional resolutions and assimilation of active remote sensing data

10 YEAR OUTCOME

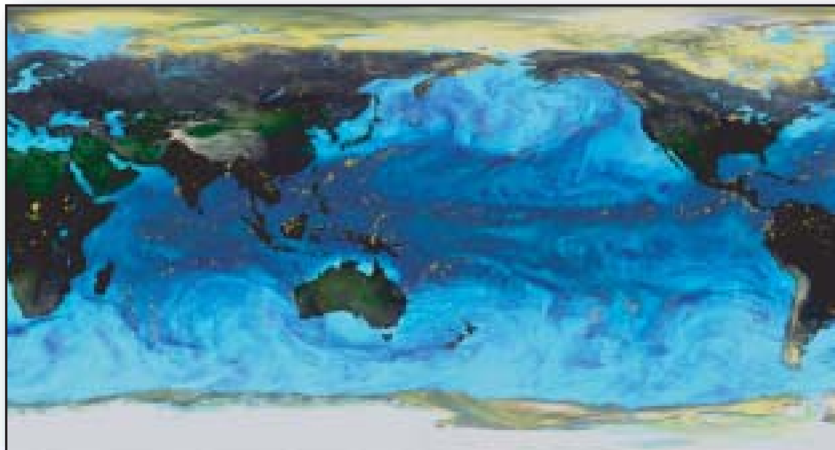
- Develop projections of future atmospheric concentrations of carbon dioxide and methane for 10-100 years into the future with improvements in confidence of >50% by 2014.
- Develop, in partnership with other agencies, credible ecological forecasts that project the sensitivities of terrestrial and aquatic ecosystems to global environmental changes by 2014 in resource management and policy related decision making.
- Report changes in global land cover, productivity, and carbon inventories with accuracies sufficient for use in the food industry, in evaluating resource management activities, and in verifying inventories of carbon emissions and storage.

YIELDS FOOD AND FIBER WE DEPEND ON

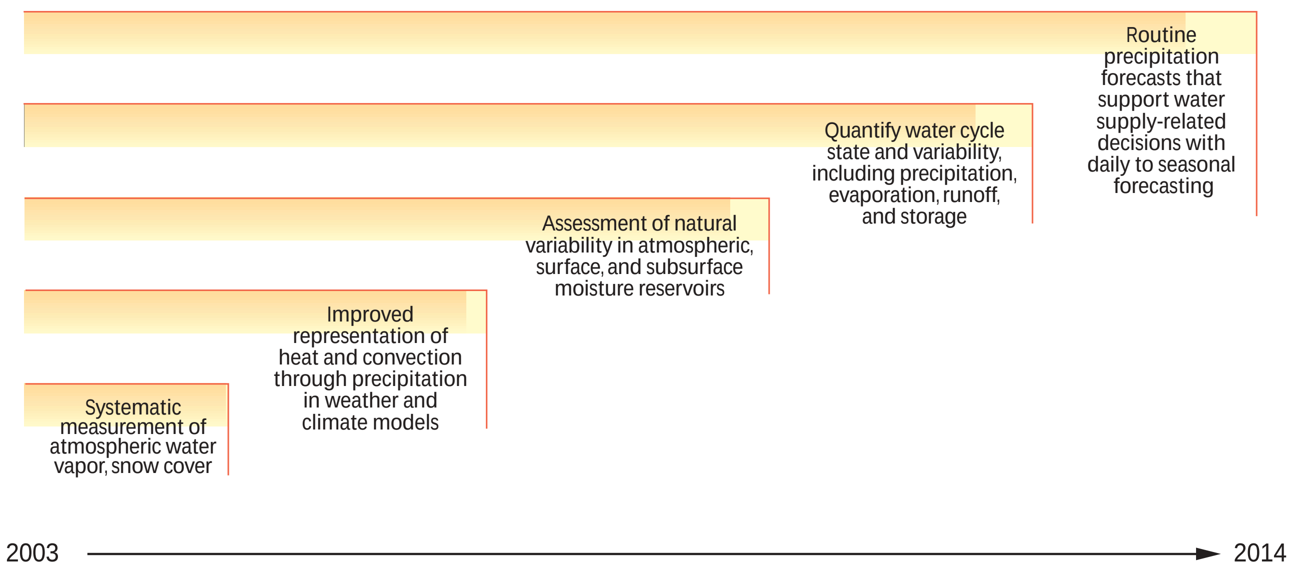


How Will Water Cycle Dynamics Change in the Future?

- Water budget balanced over global scales and long time frames to within 20%; large uncertainties on regional to local scales and annual/ seasonal time frames
- Precipitation measured over the tropics, but neither measured or predicted globally
- Soil moisture and snow water equivalent largely unknown globally



Heat radiation from a combination of sea surface and overlying moist atmosphere from AMSR-E on Aqua



Water Makes Earth Unique in the Solar System…

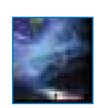
REQUIRED CAPABILITIES

	Current/Planned	*Future*
Observations		
Atmosphere	Water vapor from Aqua, NPP-Bridge Precipitation from TRMM, GPM Cloud structure from Cloudsat and ICESat	Data continuity via research and operational satellites Global monitoring of water and energy from geostationary orbit
Oceans	Sea Surface Temp from Aqua, NPP-Bridge	Data continuity via research and operational satellites
Land	Snow cover from Terra, Aqua, NPP-Bridge Hydrologic yield, evapotranspiration via Terra, Aqua, Landsat	Data continuity via research and operational satellites Soil moisture to rooting depth via satellite Global river discharge
Solid Earth	Gravity perturbations due to water distribution via GRACE	Higher resolution gravity measurement for change detection
Computational Modeling	Beginning stages of ecosystem modeling, assimilation of key new data types	10^4 times today's capability for modeling at regional resolutions and assimilation of active remote sensing data

10 YEAR OUTCOME

- Forecasts of fresh water availability and distribution useful to agriculture and water resource managers
- Seasonal forecasts of precipitation
- Snow pack and melt time prediction for planning energy generation and commerce
- Long range water cycle prediction for infrastructure planning
- Essential input to weather and climate models

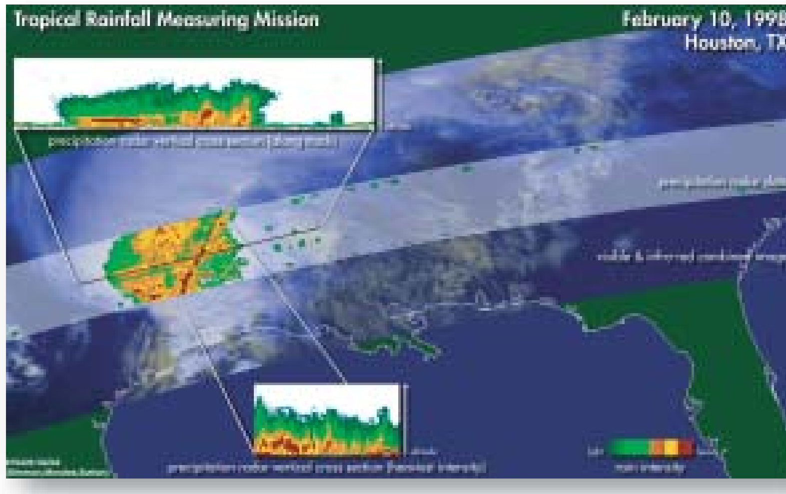
AND SUSTAINS HUMAN CIVILIZATION



How Can Weather Forecast Duration and Reliability Be Improved?

TODAY'S PRODUCTS

- 3-day forecast at 93%; 7-day forecast at 62%
- 3-day >1" rainfall forecast, low skill
- 3-day severe local storm forecast with low-moderate confidence
- Thunderstorm occurrence to 1/2 hr (within 25 nm)
- Tornado lead time 10 min
- Hurricane landfall +/- 400 km at 2-3 days
- Air quality day-by-day



KNOWLEDGE STEPS

- Steady improvement in prediction accuracy through model refinement
- Operational use of NASA satellite data beginning with ocean topography, winds and temperature data
- Satellite-derived localized precipitation/energy release will improve regional weather models
- High resolution global measurements of temperature, moisture, clouds and aerosols improve severe storm and air quality forecasts
- Global monitoring of precipitation, energy, clouds, air quality
- Transition of mature NASA research measurements to global operational forecast systems
- Global winds measurement, lightning and soil moisture assimilated for dramatic improvement in forecasts

2003 → 2014

Seeing Weather in Its Earth System Context...

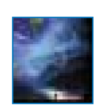
REQUIRED CAPABILITIES

	Current/Planned	*Future*
Observations		
Atmosphere	Temperature & humidity via Aqua and NPP-Bridge Precipitation via Global Precipitation Measurement	Atmospheric data continuity via research and operational satellites Geostationary sounding, imaging, lightning Tropospheric winds
Oceans	Sea surface temperature via Aqua, NPP-Bridge Ocean topography via Jason, Ocean Surface Topography Mission Ocean winds via Seawinds, Coriolis, Ocean Vector Winds Mission	Ocean data continuity via new operational capabilities
Land	Evapotranspiration via Terra, Aqua, Landsat	Soil moisture mission
Computational Modeling	NASA/NOAA Joint Center for Satellite Data Assimilation Short-term Prediction Research and Transition Center (SPoRT)	Satellite data in mesoscale models, Real-time infusion of new data into NOAA forecast process, Coupled land, ocean, and multi-scale atmospheric models

10 YEAR OUTCOME

- 5-day forecast at >90%; 7-10 day forecast at 75%
- 3-day rainfall forecast routine
- 7-day severe local storm forecast, moderate to occasional high confidence
- Thunderstorm occurrence (convective initiation) to 3 hours
- Tornado lead time 18 min
- Hurricane landfall +/- 100 km at 2-3 days
- Air quality forecast at 2 days

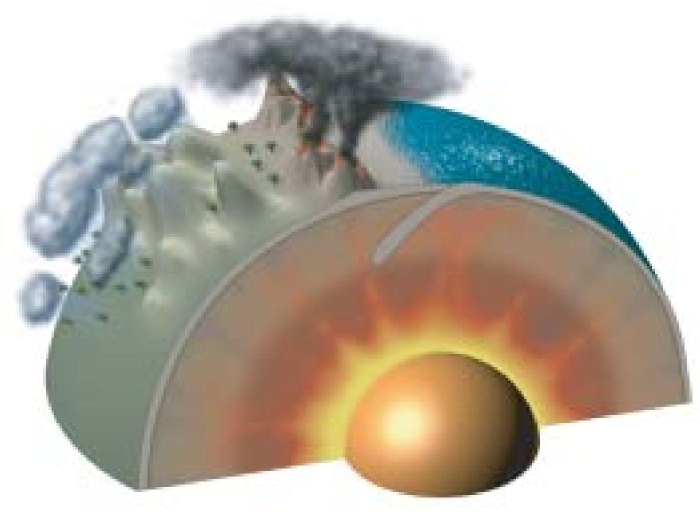
LEADS TO RELIABLE EXTENDED FORECASTS



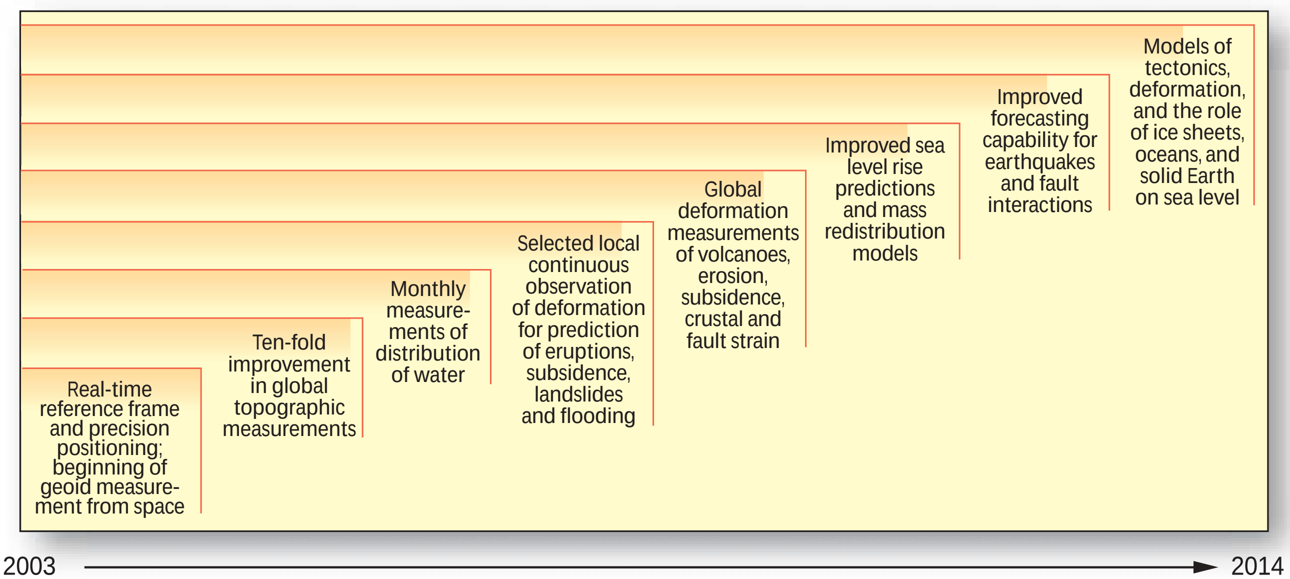
How Can Knowledge of Earth Surface Change Be Used to Predict & Mitigate Natural Hazards?

TODAY'S PRODUCTS

- Earthquake prediction only at decade to century timescales
- Eruption prediction for selected volcanoes somewhat reliable at week-to-month scales
- High uncertainty in sea level prediction



KNOWLEDGE STEPS



From Sudden, Tragic Occurrence...

REQUIRED CAPABILITIES

	Current/Planned	*Future*
Observations		
Surface deformation	GPS networks in selected areas	InSAR satellite
High resolution Topography	SRTM data, augmented with ICEsat data	InSAR satellite
Variability of Earth's magnetic field	4-6 satellites GPS constellation	Expanded GPS constellation in a variety of orbits
Variability of Earth's gravity field	Precision geoid with GRACE	Advanced gravity measurement to map Earth's interior
Imaging spectroscopy of Earth's changing surface	Continued space and airborne imaging	Improved spatial, temporal and spectral spaceborne imaging spectrometer
Terrestrial reference frame	VLBI, GPS, SLR networks	Enhanced and interconnected ground networks
Computational Modeling	Numerical modeling of interacting fault systems, mantle flow, and the geodynamo, requiring advances in computing power and software tools for efficient data assimilation and modeling	

10 YEAR OUTCOME

- Enable 30 day volcanic eruption forecasts with > 50% confidence by 2014.
- Enable estimation of earthquake likelihood in North American plate boundaries with > 50% confidence by 2014.

TO ADVANCED WARNING AND ACTION

3.1.2 Observation and Information Management Program

NASA's space observation capabilities are a central part of the Agency's contribution to Earth system science, along with the information systems which compile and organize observations and related data for research purposes. The Earth Science Enterprise has established the following strategic principles for the development and deployment of its observing and information systems:

- Design and build flexibility, agility, and stability into the integrated global observing and information management systems we create with our partners.

- Pursue new vantage points for global observation and measurement from space to gain new perspectives on the Earth system framework.

- Shift strategic focus from "missions" to "measurements"; use innovative approaches and partner support to achieve continuity in the systematic measurement of Earth system parameters to understand variability and trends; transition systematic measurements to operational systems once they are mature and compatible with partner objectives.

- Pursue advanced technologies outside of mission development to reduce impact to mission life cycle, cost and risk; e.g.:

(1) Systematic measurement systems developed to assure data continuity will use best available technology to assure consistency of long-term data records and to reduce mission costs

Partners in Land Cover and Solid Earth Science

For over 30 years, NASA and the Department of the Interior's U.S. Geological Survey (USGS) have been partners in the Landsat program. The Earth Resources Technology Satellite, later called Landsat 1, demonstrated the power of satellite remote sensing for science and applications. Successive series of Landsat satellites have provided a continuous record of global land cover change that is invaluable for global change research. The U.S. Department of Agriculture and Foreign Agriculture Office are among the largest volume users of Landsat imagery, which they and a variety of agribusinesses employ in crop monitoring and yield forecasting . Information about faults and fracture zones derived from Landsat imagery has been used in the United States and abroad to select locations for new power plants and cell phone towers, and determine the best routes for new highways and oil and gas pipelines.

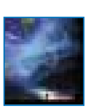
To "look" under the surface, NASA and USGS have established a network of GPS sensors in the Los Angeles basin to detect very small changes in surface displacement that both foretell and result from earthquakes. NSF, USGS, and NASA have formed the EarthScope program in an attempt to develop an analogous capability for the entire western United States. NASA's key contribution would be a space-based interferometric synthetic aperture radar (InSAR) for obtaining synoptic information about crustal deformation globally.

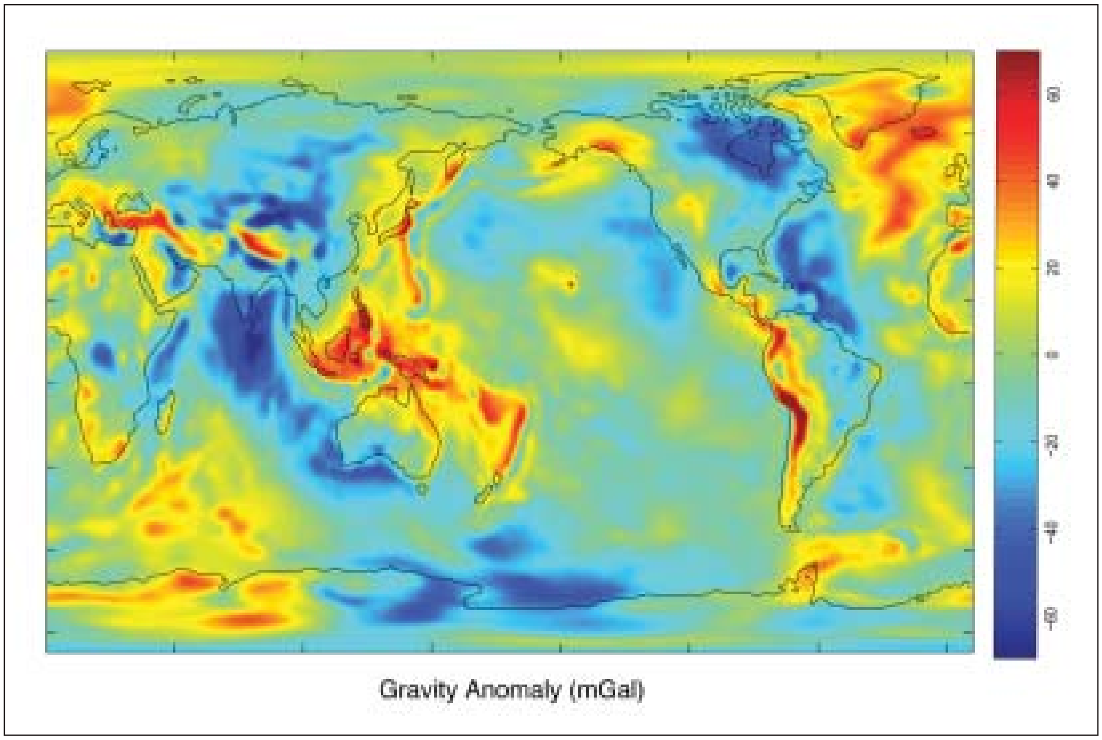
EOSDIS

The Earth Observing System Data and Information System (EOSDIS) is the largest "e-science" system in the world. Designed to operate EOS satellites and acquire, process, archive and distribute Earth Science Enterprise data and information products, EOSDIS currently handles 2-3 terabytes of new satellite data per day. In FY2002, EOSDIS distributed over 26 million data products in response to over 3.2 million user requests.

Having successfully created this system, NASA is now working to evolve it for the future while providing continuous service to the user community. In addition to new satellites and new types of data to be processed, the Enterprise's information infrastructure must also exploit rapidly advancing information and communications technologies and serve a wider variety of users. Some of those users are also part of the information infrastructure itself—science teams acquiring raw data from the system, processing it with their unique expertise and capabilities, and returning information products to be archived and/or distributed.

The Enterprise is working with the science and information technology communities to develop strategies for the evolution of Earth science data systems. We have already begun this process, first with the creation of Earth Science Information Partners (ESIPs), and now the Research, Education, and Applications Solutions Network (REASoN) of partners producing specific information products, and with the Advanced Information Technology Program. Guiding this evolution in parallel with maintaining the flow of Earth science products to their many users is a key challenge for the years ahead.





The twin spacecraft Gravity Recovery And Climate Experiment (GRACE) is yielding maps of Earth's gravity field 10 to 100 times more accurate than the best possible from conventional means. GRACE data will improve our measurements of sea level change and ocean circulation as well as yield clues to the distribution of mass in the Earth's interior including large aquifers. (NASA/JPL/University of Texas' Center for Space Research/GeoForschungs Zentrum (GFZ) Potsdam)

(2) Exploratory measurement systems using new technologies will only be selected for development when the new technology is ready

- Explore use of higher orbits as new vantage points to enhance spatial and temporal resolution while measuring key parameters of Earth system processes

- Improve national operational observing systems through infusion of new technologies and the demonstration of new measurement techniques in joint efforts between NASA and sibling agencies

- Plan and implement observing capabilities in the context of integrated national and international observing systems, commercial remote sensing capabilities, and required enabling space systems (e.g., commercial launch and communications)

- Integrate unique or new suborbital platforms into the set of assets available to the Earth Science Enterprise in collaboration with the Aerospace Technology Enterprise; partner with other science agencies and the private sector to operate and use conventional platforms

- Maintain data systems that meet today's requirements to manage terabytes of data transmissions from the Enterprise's constellation of more than 20 satellites; system must accommodate emerging measurements and technologies

- Provide and employ standards and protocols that enable participation and contributions from diverse providers and users of data and information

- Provide stewardship and distribution of research data records, and transition long-term archive responsibilities to operational agencies

- Invest in highly innovative information technology to meet Earth science requirements for data and information management, interoperability, modeling, data assimilation, scientific assessment, and decision support.

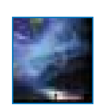
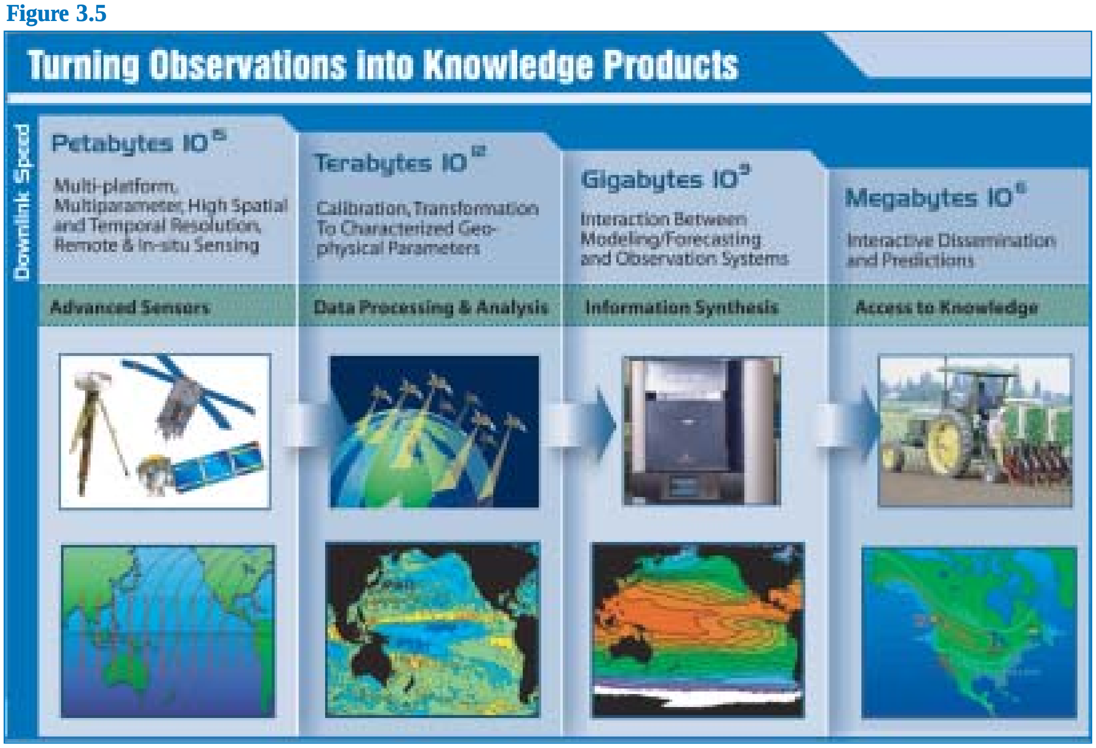


Figure 3.4

Figure 3.4 identifies the next generation of space-based observing systems which will complement the first series of the Earth Observing System. Our scientific observing strategy is described in greater detail in the Earth Science Research Plan shown in section 4. Figure 3.5 summarizes the challenge of turning vast quantities of data and information into knowledge products useful for economic and policy decision making. The Enterprise approach to data

Figure 3.5



and information management will be described at length in our upcoming Data and Information Management Plan.

3.1.3 Advanced Technology Program

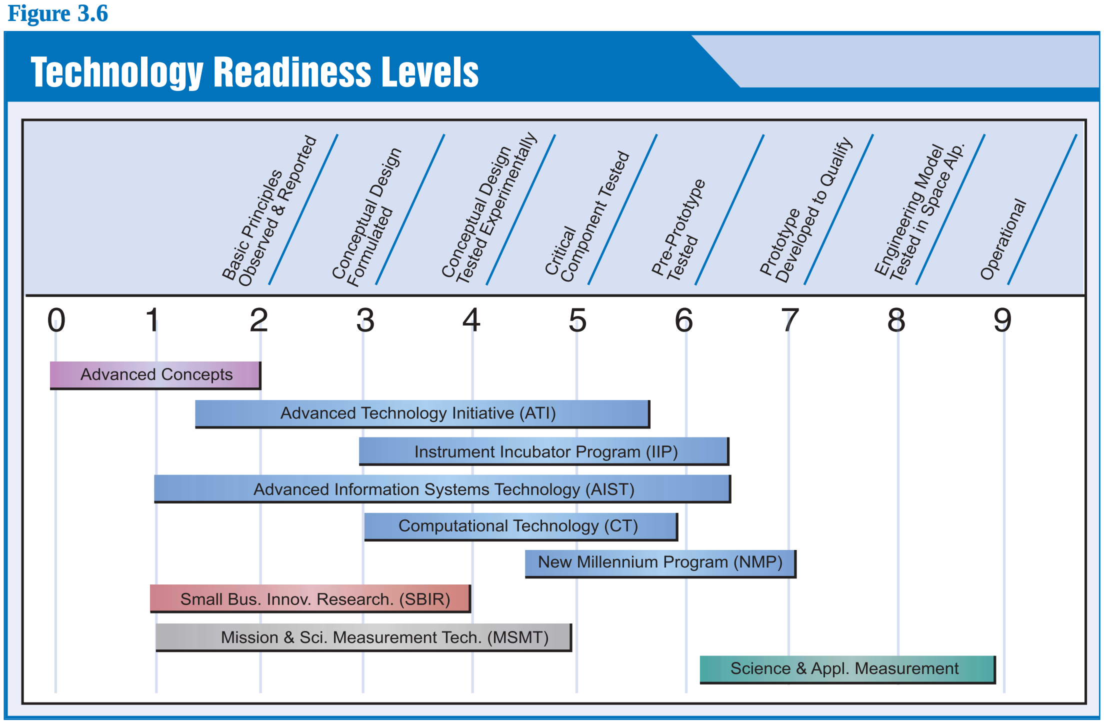
The Earth Science Enterprise's Advanced Technology program is designed to foster the creation and infusion of new technologies into Enterprise missions in order to enable new science observations or reduce the cost of current observations. Requirements for advanced technology development are based on requirements articulated in the Earth Science Enterprise Research Plan.

The Enterprise identifies technology requirements using a collaborative process of dialog between scientists, and engineers, and technology experts which is recorded and made available through a widely accessible database. This provides a basis for the management of the Enterprise technology investment portfolio.

The key components of the technology infusion process are dialog among experts and the programs spanning the technology readiness scale for remote sensing, computing, and communications. Open solicitations are used to attract the best ideas from universities, industry, and government laboratories. Conferences and workshops are facilitated to establish connections between developers of maturing technologies and scientific investigators proposing new observing or modeling approaches, and also in response to open solicitations. Principal investigators and others responding to mission solicitations can then adopt these technologies—whose maturation and readiness is well documented—in their proposals.

For example, one of the first round Instrument Incubator Program (IIP) selections was the Ocean salinity Soil moisture Integrated Radiometer-radar Imaging System (OSIRIS). This instrument concept uses a large mesh antenna with an L-band radiometer and radar combination to sense ocean salinity and soil moisture. During the latest Earth System Science Pathfinder solicitation, a proposal called HYDROS, the Hydrosphere State Mission, based directly on the IIP OSIRIS project, was received, evaluated, and selected as the alternate mission. This is an excellent example of technology development and infusion into Earth science mission concepts.

Figure 3.6



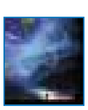
Requirements for advanced technology development are based on observing and computational modeling requirements articulated in the Earth Science Enterprise Research Plan. The following strategic principles govern the Enterprise technology program:

- Develop and adopt three technology thrust areas—remote sensing, communications, and computing—to shape the future of Earth system science research and applications.
- Enable new measurement approaches with improved spatial, spectral, and temporal resolution while reducing volume, mass, power requirements of the instruments.
- Develop and adapt advanced communications and computing technologies to facilitate the transmission, processing, and conversion of observation data into knowledge and information products.
- Select technology investments and infusion opportunities based on science needs, through competitive processes and partnerships with government agencies, universities, and industry
- Manage technology maturation through lab, field, airborne and, when necessary, in-space validation experiments and

Table 3.3

Advanced Technologies Required by Science Focus Areas

Remote Sensing Technologies	Climate Variability and Change	Atmospheric Composition	Carbon Cycle and Ecosystems	Water and Energy Cycles	Weather	Earth Surface and Interior
Advanced grating spectometer	●			●		●
Advanced broadband spectrometer	●			●		●
Advanced imaging spectrometry	●	●	●	●		●
Advanced microwave sounder		●		●	●	
Space-based multi-frequency lidar	●	●	●	●	●	●
Space-based differential absorption lidar (DIAL)		●		●	●	●
Space-based Doppler lidar	●	●		●	●	●
Multi-angle imaging spectroradiometry		●	●	●		●
Advanced radar & laser altimetry	●			●		●
Advanced thermal radiometry		●	●	●		●
Advanced microwave radiometry	●	●		●	●	●
Large aperture antenna radiometry	●			●	●	
Interferometric synthetic aperture radar	●		●	●	●	
Advanced scatterometry	●			●	●	●
Large, lightweight deplorable antennas	●		●		●	
Advanced hyperspectral radiometry		●	●			●
Advanced GPS receivers						
Laser inferometry						●
Quantum gravity gradiometer				●		●
				●		●
Computing & Communications Technologies						
Standards and interface protocols	●	●	●	●	●	●
Data mining & data fusion	●	●	●	●	●	●
High, sustained computing throughput	●	●	●	●	●	●
High volume data management	●	●	●	●	●	●
Data Visualization	●	●	●	●	●	●
On-board data processing	●	●	●	●	●	●
Data grids	●	●	●	●	●	●



demonstrations to mitigate the risk associated with the initial operational use of an advanced technology

- Manage the advanced technology development program outside of mission development to allow cross-discipline, multi-mission technology development

- Design linked technology development programs that mature promising technologies along the scale of technology readiness (figure 3.6)

Table 3.3 summarizes the key technologies required to implement the Research Plan in each of the science focus areas.

3.2 Earth Science Applications Theme

NASA's Earth Science Applications theme comprises the Enterprise's Applications and Education programs.

3.2.1 Applications Program

NASA's objective for the Earth Science Enterprise's Applications program is to expand and accelerate the realization of economic and societal benefits from Earth science, information, and technology. This objective is accomplished by using a systems approach to facilitate the assimilation of Earth observations and predictions into the decision support tools used by partner organizations to provide essential services to society. These services include management of forest fires, coastal zones, agriculture, weather prediction and hazard mitigation, and aviation safety. In this way, NASA's long-term research programs yield near-term practical benefits to society. Thus, the Applications program enables the Enterprise to be citizen-centered, results-oriented, and market-driven.

The Enterprise has chosen to focus its Applications Program on partnerships with other Federal agencies as the most efficient means to extend the benefits of Earth science information and technology to the Nation and beyond. Federal agencies such as USDA, FEMA, EPA and others have the charter to provide essential services to meet national needs. These agencies have existing webs of connections to end users in state, local, tribal, national and foreign organizations and governments to whom improvements in those services can be extended, so that NASA does not have to forge its own connections. Furthermore, Federal agencies have the information infrastructure and decision support systems capable of taking advantage of NASA's Earth science data and information. For example, the

This image shows the topography and land cover of Southern California, with the city of Los Angeles visible near the lower left and the San Andreas and Garlock Faults in the upper right. Generated from the Shuttle Radar Topography Mission and Landsat 7, data and information products such as this are available for most of the inhabited surface of the Earth, and are used in a wide variety of geophysical, geological, and hydrological research and civil engineering applications.

Federal Aviation Administration, with the aviation industry, delivers the benefits of the National Airspace System to travelers, and NASA supports that system with atmospheric observations and predictions, and with synthetic vision technologies. FEMA provides state, local, and tribal emergency managers with earthquake risk assessments using the HAZUS model; NASA helps FEMA improve HAZUS with topography, land cover change, and related data. NASA collaborates with these and other federal agencies to benchmark the capacity of Earth science research results to improve their decisions support tools so they can better serve the entire Nation.

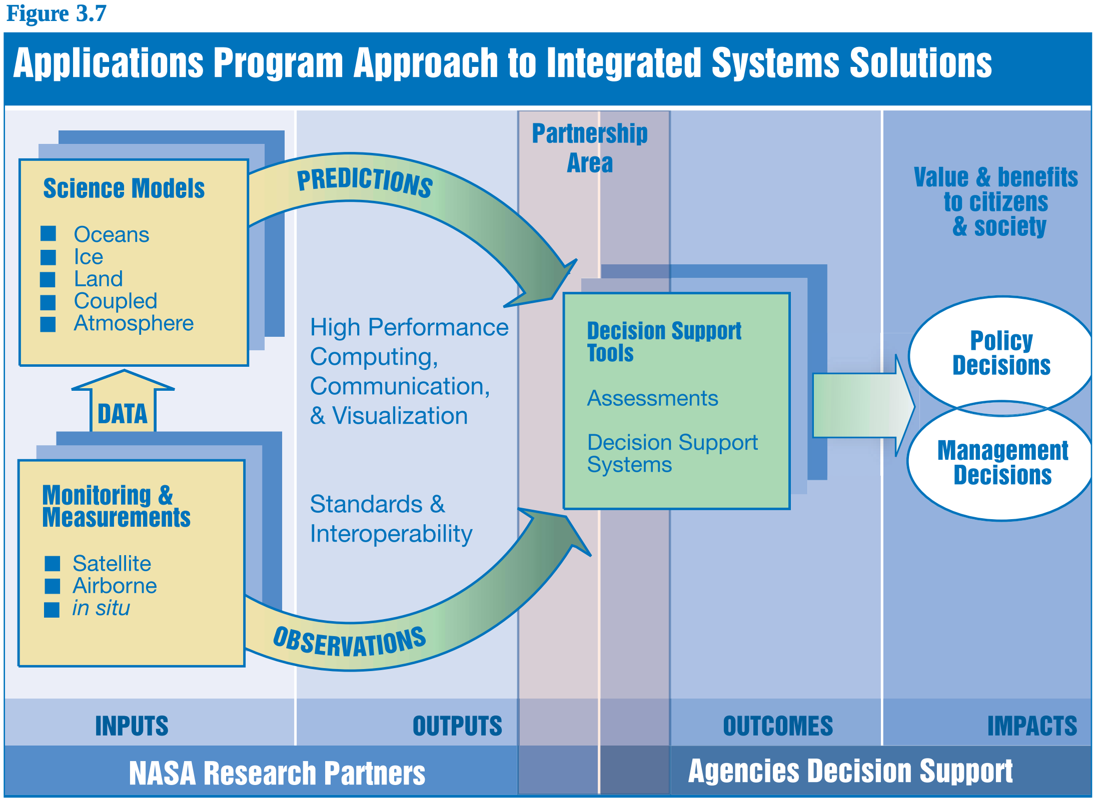
NASA remote sensing systems and Earth system models (figure 3.7) are inputs generating the observations and prediction outputs (which are inputs from the standpoint our partners decision support systems). The outcomes are improved decision support tools enabling positive impacts on national policy and management decisions in a range of activities from coastal evacuations due to hurricanes to positioning of fire fighting resources in national forests. The target impacts are improvements to the quality and effectiveness of policy and management decisionmaking by enabling decision makers to benefit from decreasing uncertainties associated with complex and dynamic Earth system processes. The shaded area indicates the bridge the Applications program and its partners build between Earth science results and decision support tools. This area is the focus of the Earth Science Applications program.

The Earth Science Applications program employs the following strategic principles in pursuit of its objectives:

- Enable the practical use of Earth science, information, and technology in ways that are systematic, scalable and sustainable, thus magnifying the benefit of Earth system science to the nation.

- Partner with other federal agencies having decision support systems that can, or can be enhanced to, assimilate observations

Figure 3.7



from remote sensing systems and predictions from Earth system models. NASA works with its partner agencies to benchmark (measure) the improvement from use of new observations and predictions.

- Employ NASA's systems engineering expertise to enable the effective assimilation of Enterprise science results, information, and technology in our partners' decision support systems

- Engage the capacity of universities, industry, and others through competitive solicitation for products, tools and techniques employing remote sensing observations and Earth system models in its sponsored applications projects.

- Engage in national efforts to coordinate geospatial information principles and practices (interoperability, standards, metadata, etc), such as the Geospatial OneStop (*http://www.geodata.gov*) and the Federal Enterprise Architecture, to assure the utility of the vast quantity of data collected by the several agencies engaged in in situ, airborne, or satellite remote sensing.

- Employ the national Commercial Remote Sensing Policy as a guide to the acquisition and use of commercially available remote sensing data for research and applications.

The Earth Science Enterprise is engaged in 12 national applications with partner Federal agencies that can significantly benefit from NASA's observations and research results. The 12 applications of national priority are shown in table 3.4.

Building on the science focus area roadmaps, the Earth Science Enterprise's Applications program has developed roadmaps for each of the 12 national applications. Whereas the science focus area roadmaps call for continued and new observing and prediction capabilities, the Applications roadmaps link planned capabilities to specific solutions. The Applications roadmaps are developed in preparation for and implementation of formal agreements between NASA and other Federal agencies that want to employ new Earth observations and scientific results in their decision support systems.

These 12 applications draw from research in the 6 science focus areas, as shown in figure 3.8.

Figure 3.8

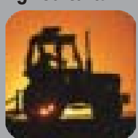
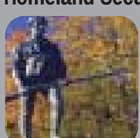
Earth Science Research & Applications Matrix

	Carbon Management	Public Health	Management Energy	Aviation	Water Management	Homeland Security	Coastal Management	Disaster Management	Agricultural Efficiency	Invasive Species	Ecological Forecasting	Air Quality
Atmospheric Composition	◐	●		◐		◐			◐			●
Carbon Cycle & Ecosystems	●	●	◐				◐		●	●	●	
Climate Variability & Change	◐	●	●		◐		●	◐	◐	◐	◐	◐
Earth Surface & Interior				●	◐	●	◐	●				
Water & Energy Cycles	◐		●		●		●	◐	●	◐	◐	
Weather			●	●	◐		◐	●	●			◐

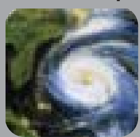
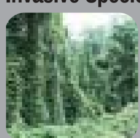
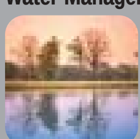
● Primary Linkages ◐ Secondary Linkages

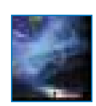
Table 3.4

National Applications

National Application	Partner Agency(s)	NASA Contributions	Partner Agencies Decision Support Tools	Decadal Outcomes of Agencies Use of NASA Data and Information
Renewable Energy 	DOE, EPA	Extended weather forecasts, seasonal climate prediction, and distribution of incoming solar radiation via Terra, Aqua, SORCE, Cloudsat, NPP, GPM	• RETScreen • Natural Resources Canada (NRCan)	• Renewable energy sources and their integration into the power grid through use of RETScreen • Location of renewable energy facilities • Biomass crop selection and maintenance strategies
Agricultural Efficiency 	USDA, EPA	Seasonal temperature and precipitation, extended weather forecasts, and soil moisture via GPM, Aqua, Terra, NPP, Landsat, Aquarius, suborbital	• Crop Assessment Data Retrieval and Evaluation (CADRE)	• Improved crop production assessments • Increased agricultural productivity and reliability
Carbon Management 	USDA, EPA, DOE, USGS, USAID	Measurement of carbonaceous gases and aerosols, terrestrial biomass and marine productivity via Terra, Aqua, Aura, NPP, OCO, suborbital	• Tools developed to implement Section 1605(B) of Energy Act of 1992 (EA92): voluntary sequestration of greenhouse gases	• Operational decision support system with improved assessment of carbon sources and sinks for a carbon trading regime
Aviation 	DOT/FAA	Improving weather nowcasting, monitoring of volcanic aerosols via Terra, Aqua, NPP–Bridge, GPM, suborbital; improve cockpit capabilities via: • Aviation Weather Information Network (AWIN) • Synthetic Vision System (SVS)	National Airspace System (NAS): • Controller/pilot decision aids • Runway incursion prevention	• Enhanced National Airspace System, AWIN, and SVS that reduce the aviation fatal accident rate by a factor of 10 by 2022 • Improved operational efficiency in a 2:1 ratio
Homeland Security 	DHS, NIMA, USDA, USGS, NOAA, DoD	Observation and modeling of atmospheric chemical transport and precipitation via Terra, Aqua, NPP, GPM, suborbital	• Department of Homeland Security (DHS) Situation Control	• Improved capabilities of homeland security officials to prepare, warn, and respond to homeland security threats, especially air and water exposure
Ecological Forecasting 	USGS, USDA, USAID	Observation of land cover change, vegetation structure, and biomass, and use in ecosystem models via Landsat, NPP, suborbital	• Models of habitat change • Impacts of El Niño and other oceanic oscillations on fisheries • Regional visualization and monitoring system for the Mesoamerican Biological Corridor	• Enhancing ecosystem sustainability as economics and populations shift and grow

National Applications—Continued

National Application	Partner Agency(s)	NASA Contributions	Partner Agencies Decision Support Tools	Decadal Outcomes of Agencies Use of NASA Data and Information
Disaster Preparedness 	FEMA, USGS, NOAA, USDA	Observations of topographic change and crustal strain and motion, extended weather forecasts via Aqua, SeaWinds, SRTM, InSAR, Landsat, GPM, suborbital	• HAZUS Risk Prediction • Center for Integration of Natural Disaster Information (CINDI)	• Enhanced risk assessment, warning and response for hurricanes, tornados, flooding, earthquakes, and landslides
Public Health 	CDC, DoD, NIH, EPA, USGS, NOAA	Observations and modeling of weather, climate and other environmental factors influencing disease vectors and air quality via Aura, NPP, Jason, GPM	• Environmental Public Health Tracking Network (EPHTN) • Arbovirus Surveillance Network (Arbonet) • Malaria Modeling and Surveillance (MMS)	• Improved surveillance systems (Arbonet) • Integrated environmental factors into EPHTN • Improved accuracy and precision of disease predictions with a corresponding increase in warning time
Coastal Management 	NOAA, EPA	Measurement and modeling of ocean temperatures, winds, color and salinity associated with harmful algae blooms via Terra, NPP, SeaWinds, Landsat, Jason	• Harmful Algal Bloom Mapping System/Bulletin (HABMap/Bulletin)	• Improved capability of decision support systems to forecast HAB initiation, transport, toxic severity, landfall, and demise
Invasive Species 	USGS, USDA	Observations and modeling of land cover change, biomass and climate influencing species proliferation in areas where newly introduced, via Terra, Aqua, NPP, Landsat	• Invasive Species Forecasting System (ISFS)	• Operational, robust, and early detection and monitoring of plant invasions to protect natural and managed ecosystems
Water Management 	USBoR, EPA, USDA, USGS	Improved models of water transport, storage and quality using observations of snow cover, soil moisture, and topography via Aqua, NPP, GRACE, GPM, Landsat, suborbital	• RiverWare • Better Assessment Science Integrating Point and Nonpoint Source (BASINS) • Agricultural Water Resources and Decision Support (AWARDS)	• Improved water quality and quantity assessments • Forecasts of precipitation and daily crop water use towards reduction of real-irrigation • Seasonal predictions for optimum vegetation selection and improved water use efficiency
Air Quality 	EPA, NOAA, USDA, FAA	Measurements of aerosols, ozone, CO and CO2, and modeling of aerosol and chemical atmospheric transport via Terra, NPP, Aura, OCO, Glory, suborbital	• Community Multiscale Air Quality modeling system (CMAQ) • Air Quality Index	• Multiple-day air quality forecasts and robust emissions control planning



The Earth Science Applications program purpose, approach, and intended outcomes are consistent with the recognition by both the U.S. government's Executive and Legislative branches of the value of using Earth science, information and technology to improve the many decision support systems employed by the public and private sectors to deliver essential services. The Climate Change Science and Technology Programs have both embraced the paradigm of observing systems to models to decision support systems, underpinned by research, as a structured means of delivering science for society. This basic approach is also serving as one basis for the next phase of international collaboration on Earth observation. The beginning of this new phase was marked by the international Earth Observation Summit held in July 2003, which inaugurated planning for a global Earth observation system aimed at providing environmental information necessary for improving quality of life and the stewardship of planet Earth.

3.2.2 Education Program

The Earth Science Enterprise's Education program systematically extends NASA's results in Earth system science and the development of remote sensing and geospatial technologies to support national priorities for science, technology, engineering and mathematics (STEM) education through partnerships with educational institutions and organizations. The Education program also participates in the educational activities of international organizations engaged in global sustainable development.

The Enterprise's Education program is conducted in close collaboration with NASA's Education Enterprise to optimize the Enterprise contribution to the agency's Strategic Goals, Objectives and Outcomes for education. The Earth Science Enterprise contributes to NASA's education mission by inspiring the next generation of Earth explorers. The Enterprise views the concept of Earth explorers broadly. The elementary school student questioning if El Niño events happen in oceans other than the Pacific; the researcher investigating the relationship between Arctic ozone depletion and global climate change; the consumer comparing hydrocarbon-powered and hydrogen-powered cars; and the businessperson projecting future needs for harvest, transport and storage of crops are all Earth explorers. All share a vital interest in Earth system processes and the impact these processes have on sustaining life on Earth for future generations.

The Enterprise's Education program makes the discoveries and knowledge generated by the Enterprise accessible to students and the public through a balanced portfolio of elementary and secondary, higher, and informal education programs. The elementary and secondary program draws upon the compelling nature of Earth system science to promote student achievement and enrollment in STEM courses through curricular support and teacher professional development. The higher education program ensures the development of a highly qualified and diverse workforce for Earth system science research and

Joint Center for Satellite Data Assimilation

Data assimilation combines observations from diverse sources with a physical model to produce and optimal estimate of the state of the Earth system and prediction of its future state. The Enterprise has a key role in data assimilation research within U.S. climate and weather research programs (e.g. CCSP and USWRP).

A recent report by the NRC Commission on Geosciences, Environment and Resources (2000) highlighted the obstacles inherent to the transition from research to operations in weather satellites and numerical weather prediction. The report referred to this problem as "crossing the valley of death." NASA and NOAA recently established the Joint Center for Satellite Data Assimilation (JCSDA) to confront this issue. The JCSDA mission is to accelerate the use of observations from Earth-observing satellites in weather and climate prediction models.

The goals of JCSDA are to reduce from two years to one year the average implementation time for new satellite technology, improve use of current satellite data in weather and climate forecast systems, and assess the impacts of satellite data on weather and climate predictions. The emergence of JCSDA comes at a critical time since a five-fold increase in satellite data is expected by the end of the decade. In January 2002, NCEP began to incorporate NASA's QuikSCAT data. NCEP estimates that QuikSCAT data have led to a 3-8 percent improvement in 10 m winds versus mid-latitude deep ocean buoys at 24-96 h and 7-17 percent improvement for mean sea level pressure (MSLP).

Earth science applications by supporting both the continued training and early careers of aspiring interdisciplinary Earth system scientists and the development of opportunities for engaging undergraduates and graduate students in Earth system science research and education. The informal education program increases overall scientific literacy of Earth system science and climate change by engaging the public in shaping and sharing the experience of NASA's exploration and discovery. In all Enterprise Education programs there is an emphasis on inspiring and supporting underrepresented and underserved communities and improving the effectiveness of education technology.

Some expamples of Earth Science Education programs include:

Elementary and Secondary Education

- **GLOBE.**—The GLOBE program (*http://www..globe.gov*) unites students, teachers and scientists in Earth system research and education. Students take measurements in the fields of atmosphere, hydrology, soils, and land cover/phenology. They report and analyze data sets through the Internet and collaborate with scientists and other GLOBE students worldwide. GLOBE operates in all 50 states and in 103 countries around the world.

- **Earth System Science Education Alliance (ESSEA).**—Teachers earn graduate credit while solving problems, learning Earth system science concepts, designing classroom activities, and collaborating with colleagues separated by large geographic distances through participation in the ESSEA program (*http://www.cet.edu/essea/*). ESSEA supports 20 institutions of higher education in their offering of online Earth system science courses. As of Spring 2003, over 800 teachers across the United States have completed one of three 16-week courses for elementary and secondary educators.

Higher Education

- **Earth System Science Education for the 21st Century (ESSE 21).**— Undergraduate faculty across the country collaborate under the auspices of ESSE 21 (*http://esse21.usra.edu*) to advance undergraduate interdisciplinary education. To date, faculty and students from 57 universities and colleges are active participants in the ESSE 21 community. The ESSE 21 community develops Earth system science courses and degree programs, integrates Earth system science into teacher education courses, and has created a faculty "handbook" to promote and facilitate the incorporation of systems thinking throughout Earth system science education programs.

- **Training Leaders in Earth System Science.**—The Earth Science Enterprise operates a graduate fellowship program and an early-career program to ensure the continued training of interdisciplinary

scientists to undertake Earth system research and prediction. Since the establishment of the Earth System Science Fellowship Program in 1990, over 600 students have received their master and/or Ph.D. degrees in disciplines comprising Earth system science. NASA's New Investigator Program (NIP) in Earth Science supports early career scientists and engineers in the development of their research activities. NIP participants contribute to the improvement of science education and public science literacy by integrating research and education. These individuals extend their understanding of Earth system science to support policy and management decisions and have begun to form a network to continue to advance Earth system science and Earth science applications nationwide.

Informal Education

- **Museums Teaching Planet Earth**.—This growing collaboration with science museums enriches students' educational experiences directly through planetarium shows and museum exhibits, and indirectly through teacher professional development programs. For example, millions of people have interacted with museum exhibits at the National Museum of Natural History, the American Museum of Natural History, the Houston Museum of Natural Science and other institutions.

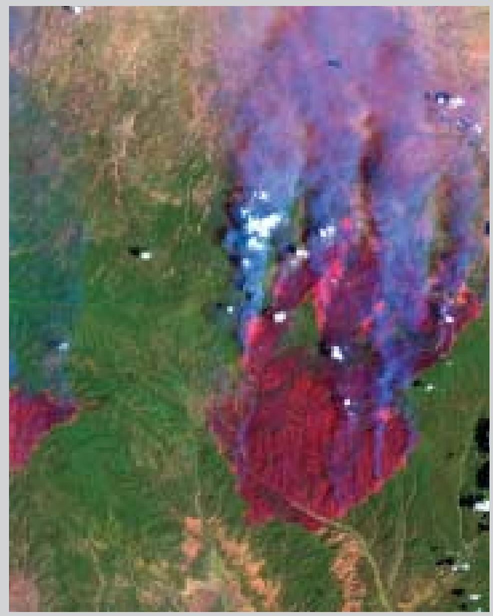
- **Global Climate Change and You**.—Global Climate Change and You is a workshop series for Girl Scout leaders. Through fieldwork and hands-on activities, leaders develop the skills and experience needed to confidently engage their troops in Earth system science.

The Enterprise approach for inspiring the next generation of Earth explorers has two essential elements. The first is to provide an architecture for systematically delivering unique Earth Science Enterprise educational materials and training for routine use by formal and informal educators and learners. The second is the formation of networks of partnerships with educational institutions and organizations in formal and informal education communities. This approach provides a framework for the development, widespread dissemination and effective use of Enterprise programs and resources. It supports scalable, sustainable and systemic solutions for Earth system science education. Scalable solutions enable benefits to audiences beyond the initial recipient. Sustainable solutions extend capacity beyond the initial funding period. Systemic solutions employ systems infrastruture to support educational administrators and lead to lasting change in how STEM education is approached and perceived.

Earth Science Data and Models Serve Fire Response

The NASA MODIS sensor supports research to examine land, sea, and air processes to improve global, interactive Earth system science models. MODIS measurements also provide information and products to support operational fire management responsibilities of the US Forest Service the National Interagency Fire Center.

Based on the effectiveness to actively detect fires, NASA, the USFS, and others developed a rapid response service to produce burn maps. The measurements also feed fire prediction models that simulate fire intensity, spread, and height and provide maps of fire perimeter and direction. This information allows managers to direct people and equipment in efficient ways.



Partnerships are integral to the overall success of the Earth Science Education program as they leverage program resources and are the basis of the national program for STEM education. For example, through a partnership with the Digital Library for Earth System Education (DLESE, *http://www.dlese.org*), a National Science Foundation-sponsored program, the Enterprise contributes to the quality, quantity and efficiency of teaching and learning about the Earth system. DLESE provides access to high-quality education resources and services through a community-based, distributed digital library. The Earth Science Enterprise partners with the American Geological Institute by providing content for and participating in their Earth Science Week (*http://www.earthscienceweek.org*). Earth Science Week is a national and international event that helps the public gain a better understanding and appreciation for the Earth sciences and encourages Earth stewardship. The Enterprise partners with textbook publishers to provide relevant and stimulating STEM content within an Earth system science context for new science textbooks.

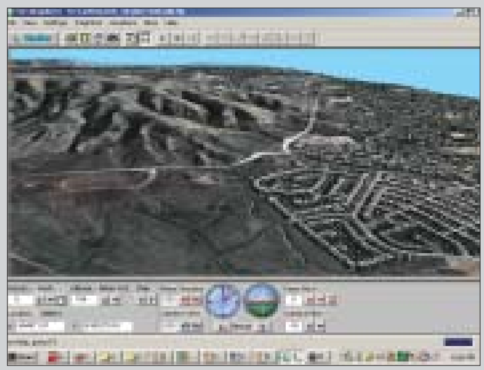
This section has outlined the strategy for realizing "science for society" in the Enterprise's five key programmatic elements: Research, Observations and Information Management, Advanced Technology, Education, and Applications. Together they compose an end-to-end, systematic approach to answering Earth science questions for which remote sensing can make a defining contribution, and facilitating the broad use of this new knowledge.

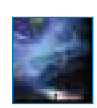
Atmosphere and Terrain Information Support Aviation Safety

Enhanced predictions of weather and atmospheric conditions contribute to aviation safety. Cockpit Synthetic Vision Systems incorporate advanced terrain and atmospheric conditions to enhance a pilot's situational awareness.

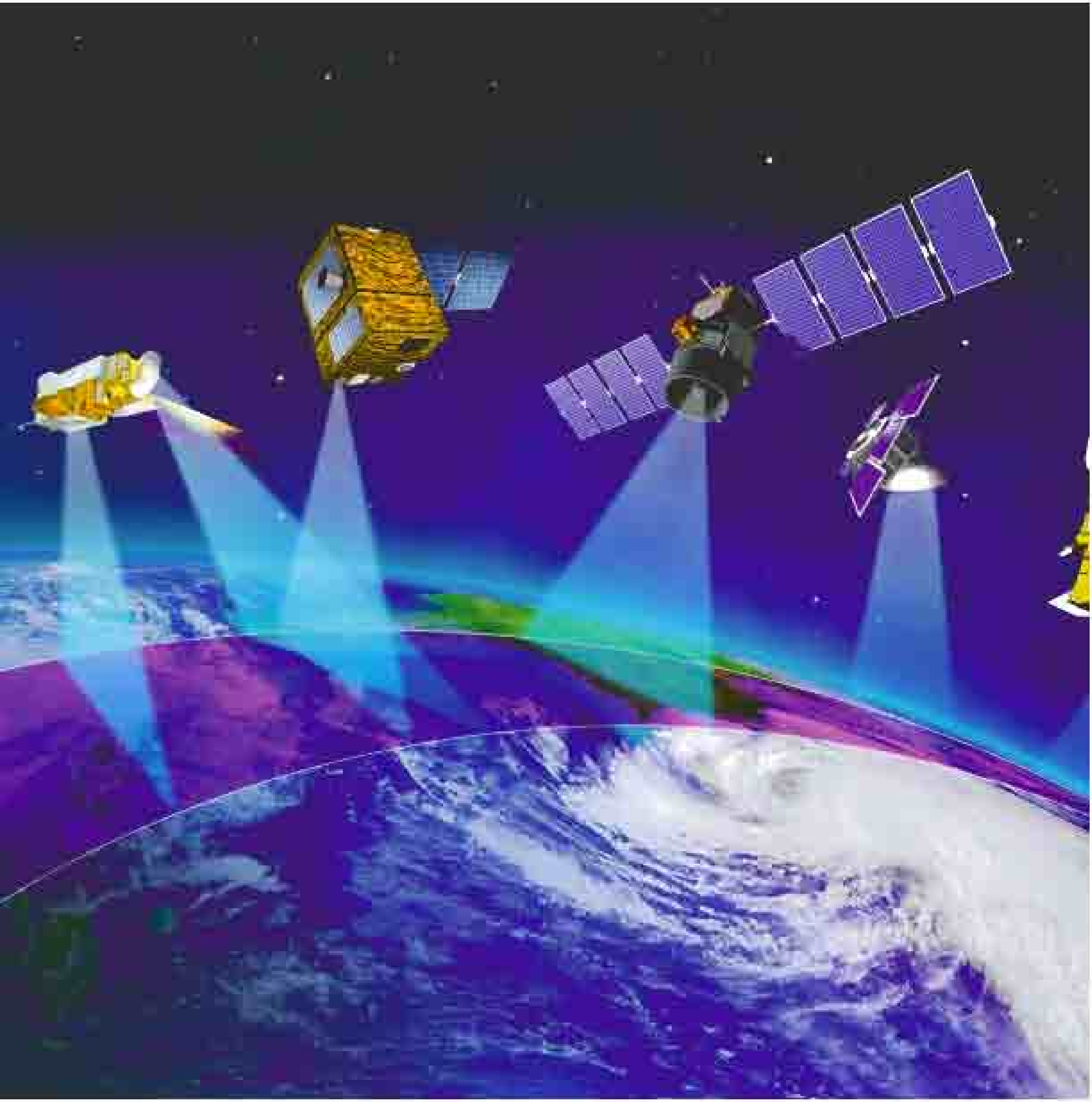
A study of use of Synthetic Vision Systems at 10 U.S. airports forecast savings of $2 billion annually at those airports alone.

Plans to improve atmospheric measurements further will assist forecasters locate and track severe weather predictions in greater detail. Great specificity of the location of turbulence and severe weather provides more options for rerouting aircraft and less disruption to the air traffic system.





4 Strategy Implementation

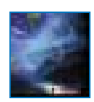


4 Strategy Implementation

These are exciting times in Earth science. We have for the first time a comprehensive observing system capable of probing the interactions of the major components of the Earth system. We have gained an understanding of the Earth system sufficient to create our first computational models that include most of the Earth system processes, and the real-world observations to set the initial conditions and changed conditions for model runs and test their output. We are creating information pathways that channel our observations and model results into the decisionmaking processes of a wide variety of organizations that provide essential services to the Nation and the international community.

NASA is poised for great progress in the years ahead. We are now operating networks of satellites that form constellations with unprecedented combined capabilities. We have come this far by creating an end-to-end programmatic approach comprised of Research, Observation and Information Management, Advanced Technology, Applications, and Education; and we have built a network of partnerships equal to the task of observing and understanding the complex Earth system. These partnerships will be even more important as we probe deeper and extend more broadly the benefits of our research. This section describes NASA's prioritization criteria, Enterprise plans, and essential partnerships.

The "A-train" formation of atmospheric remote sensing satellites Aqua, Parasol (France), CALIPSO (with France), Cloudsat, Aura, and the Orbiting Carbon Observatory. Flying these satellites in formation will facilitate the integration of their data on clouds, aerosols, and atmospheric properties and chemical composition into greatly enriched scientific information products.

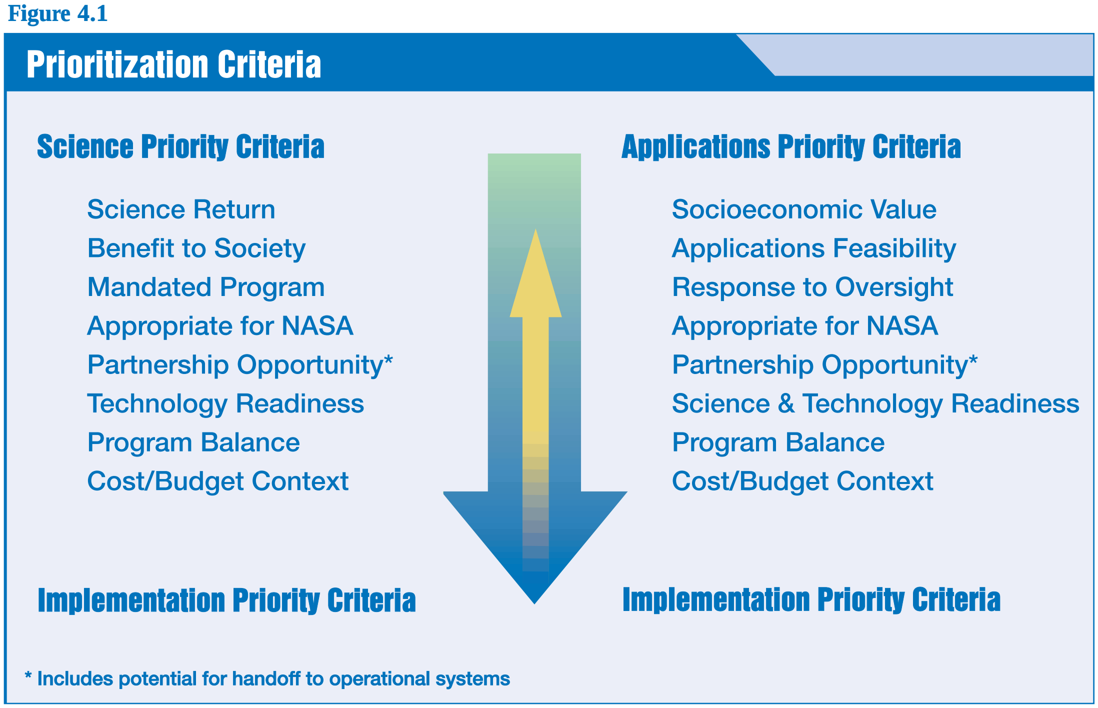


Earth System Science results are widely employed in environmental decisionmaking and in training the next generation of scientists and engineers

4.1 Prioritization Criteria

Establishing research priorities becomes a major challenge when priorities cross a number of different disciplines, each embracing a large set of scientific questions. The challenge facing the Enterprise is to balance competing demands in the face of limited resources and chart a program that addresses the most important and tractable scientific questions and allows optimal use of NASA's unique capabilities for global observation, data acquisition and analysis, and basic research. To this end, choices must be made between many

Figure 4.1



projects, all of which are important, timely, and ready to succeed. Most significant from a strategic perspective are the choices between different but equally promising candidate space flight missions or measurement systems.

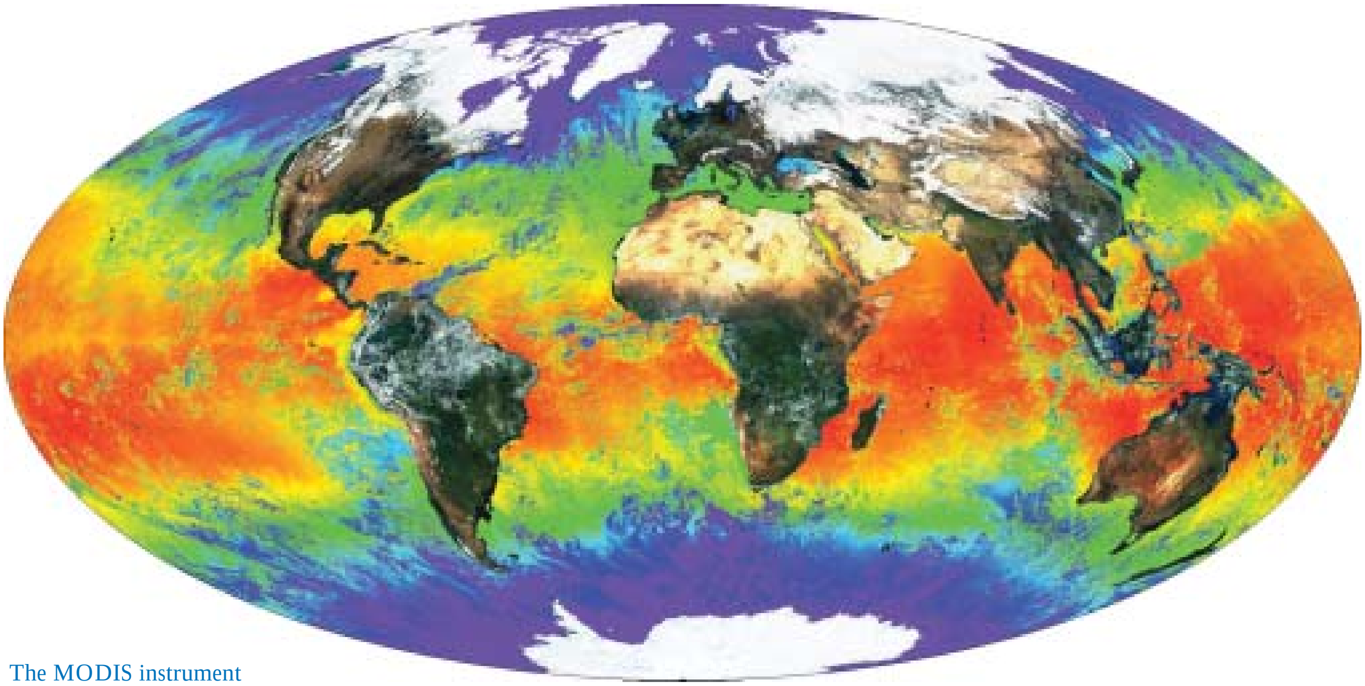
Figure 4.1 shows the prioritization criteria from both the Research and Applications perspectives. The lists of criteria are not ordered by importance in all cases; rather, it is presented in a logical order of procession as project concepts are conceived and matured. NASA's selection of priorities involves both scientific needs and implementation realities. From the Research perspective, scientific considerations are paramount and start the prioritization process. These considerations determine what science questions, and ultimately which research projects (modeling, observations, process studies), should be pursued. Purely scientific merits are followed by considerations of science-related context (e.g., benefit to society, mandated programs), followed in turn by implementation considerations. The latter criteria, such as technology readiness, tend to impact the order in which science projects are pursued and the final shape they may take. These practical considerations result in some feedback and iteration of project selection. From the Applications perspective, benefit to society as measured by socioeconomic value is the starting point, followed by the feasibility of the application from a scientific maturity. Implementation considerations similar to those for science are employed to refine ultimate project choices.

4.2 Enterprise Plans

This Strategy guides a family of Enterprise-level plans as shown in figure 4.2. These documents describe how the strategic principals discussed in section 3 will be implemented. Each of these documents will be accessible at the *earth.nasa.gov* Web site.

The Enterprise is mobilizing its network of partnerships to layout and implement roadmaps in each of the six science focus areas. The roadmaps, summarized previously on pages 28-39, provide a tool for end-to-end program planning, development, implementation and integration, structured collaboration, program evaluation, and identification of core competencies to be maintained or strengthened. Roadmap progress is achieved through specific observation, modeling, and data management projects selected through

Figure 4.2



The MODIS instrument on the Terra and Aqua satellites provides frequent (every 1-2 days) global views of many of the Earth's vital signs. This image shows a false-color land surface, derived using MODIS' Surface Reflectance Product, and a false-color sea surface temperature map (red and yellow are warmer, blues are cooler).

open solicitations and peer review processes, managed by the Enterprise's Headquarters staff and NASA's Research and Space Flight Centers.

The Earth Science Enterprise office at NASA Headquarters administers program selection and formulation and manages the Enterprise's Research and Applications programs, with active participation from selected NASA Centers. Partnerships with international space agencies, other Federal agencies, and other organizations are sought and managed at this level. Individual programs and projects are assigned to Centers to manage. A broad range of collaborations with domestic and international partners enable the implementation of the Enterprise Strategy.

4.3 Partners

Within NASA, our Research and Space Flight Centers are the engines of progress in Earth system science. Scientists at these Centers conduct leading-edge research as well as enable research performed at the Nation's universities. They assure the scientific quality of our satellite and suborbital observing programs. The Centers are program and project managers and implementers, developing and adopting advanced technologies and integrating them into Enterprise-sponsored research missions. The Centers roles and missions in the Earth Science Enterprise are summarized in figure 4.3.

NASA Centers also play essential roles in other aspects of the program. For example, Goddard Space Flight Center (GSFC) hosts the Earth Science Technology Office, which meets Enterprise needs for advanced technology through a web of partnerships with universities, industry, and other government laboratories. Stennis Space Center (SSC) manages applications verification and validation activities in support of NASA and private sector commercial remote sensing systems. Ames Research Center (ARC) provides information technology to advance our computational modeling capability, as well as suborbital science mission management. The Jet Propulsion Laboratory (JPL) manages the New Millennium advanced technology demonstration program in support of both the Earth Science and Space Science Enterprises flight demonstration of advanced technologies. GSFC manages the Enterprise's development data and information system and GSFC, JPL, and Langley Research Center (LaRC) host Earth Science Distributed Active

Archive Centers. Dryden Flight Research Center (DFRC) and GSFC/Wallops Flight Facility support all the science focus areas with suborbital platform operations.

Our greatest strength is our workforce, who are essential to the achievement of our goals and objectives. The Agency faces skill imbalances, an aging workforce, and the potential loss of knowledge as employees retire. We will actively support implementation of the Agency Strategic Human Capital Management Plan to ensure that we continue to attract and sustain a high-performing diverse workforce. We will work to identify the human capital competencies required for today and the future, and define the competencies that must be retained internally and those that can be supplied by industry, universities, and external organizations. We are committed to the training and development of our existing workforce through formal and informal training and will promote knowledge sharing and mentoring activities to ensure that the valuable experience of our senior people is shared with those who follow. We will assist in addressing the shrinking pipeline of scientists, engineers, and technologists and the future need for a diverse pool of talent through our education activities.

The Earth Science Enterprise will ensure that its Centers develop and sustain the facilities and infrastructure needed to carry out the goals and objectives of the Enterprise and the NASA Vision. Following the concepts and strategies of the NASA Facilities Engineering Functional Leadership Plan and the Agency's Real Property Strategic Plan, the Enterprise will work with the Facilities Engineering Division to develop programs and plans for the continual improvement of mission and program support. The requirements will be incorporated into the Center Implementation Plan (see appendix 1), supported by the Center master plan.

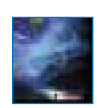
Figure 4.3

NASA Center Roles in Earth Science

	Climate Variability & Change	Atmospheric Composition	Carbon Cycle Ecosystems	Water & Energy Cycle	Weather	Solid Earth
GSFC	●	●	●	●	●	○
JPL	●	●	○	○	○	●
SSC			○			
LaRC	○	●		●	○	
ARC	○	○	○			
MSFC	○		○	○	●	
DFRC	○	○	○	○	○	○

● = Primary ○ = Supporting

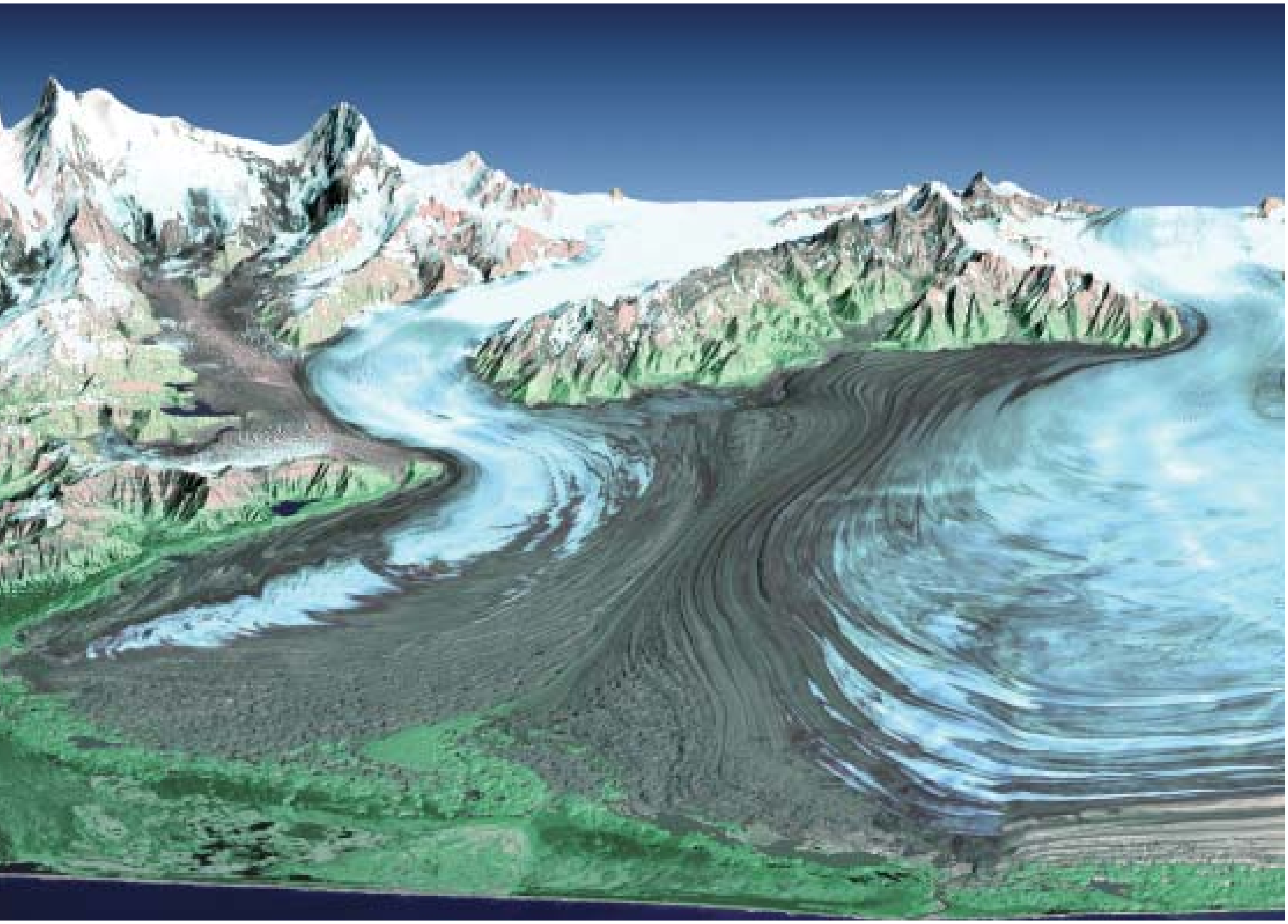
- GSFC and JPL develop space-based observing missions
- GSFC hosts the Earth Science Technology Program
- SSC performs system engineering for the Applications Program
- DFRC and GSFC/WFF supports all science focus areas with sub-orbital platform operations
- ARC is a principal source of advanced information technology



The NASA team extends beyond the Centers to the many scientists and engineers around the Nation that are directly involved in conducting research, designing and developing satellite missions, inventing new technologies, and helping to communicate research results in ways that are useful to society. Teams of university and Center scientists, for example, enhance the scientific quality of data from Earth observing satellites by creating algorithms, performing calibration and validation, and constructing data records and visualizations of Earth system change.

We also work with other NASA Enterprises toward the common Agency Vision and Mission. For example, we work closely with the Space Science Enterprise to study the Sun-Earth connection to understand the causes of solar variability and its impact on the Earth system. We collaborate with space scientists to adapt Earth system models to the goal of exploring the universe in astrobiology. The Aerospace Technology Enterprise provides us with new suborbital platform technologies on which to fly science instruments in Earth's atmosphere, and

Glaciers are sensitive indicators of climatic change. They can grow and thicken with increasing snowfall and/or decreased melting. Conversely, they can retreat and thin if snowfall decreases and/or atmospheric temperatures rise and cause increased melting. Data from Landsat and elevation model data from the Shuttle Radar Topography Mission (SRTM) are combined to create this three-dimensional view of the Malaspina Glacier in southeast Alaska.



we assist their efforts to improve aviation safety. In addition, the Aerospace Technology Enterprise's Mission and Science Measurement Technology program is one key source of advanced technologies for Earth science. We work with the Biological and Physical Research Enterprise in the study of the human health effects of global change. The Space Flight Enterprise provides access to space as well as new, human-tended platforms that enhance robotic Earth observation. The Education Enterprise coordinates the efforts of all the Enterprises in helping to improve science, technology, engineering and mathematics education in the United States.

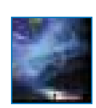
Within NASA, the Agency Program Management Council provides advice, counsel, and recommendations for consideration by the Administrator through the Associate Deputy Administrator for Technical Programs relating to planning, implementation, and management of all major Agency programs. This Council also provides a forum to involve the highest level of program officials in addressing issues pertaining to program and project management policy and implementation. The Agency Program Management Council evaluates the integrated planning, approval, and implementation of Agency programs to ensure that programs are consistent with Agency strategic planning, available resources and are conducted in accordance with the established commitments. The Earth Science Enterprise Program Management Council is the highest level management control council within the Enterprise, to manage and control the science, applications, technology, and programmatic aspects and baselines of the Enterprise. A baseline is the mission (project) budget profile, technical performance requirements, and schedule defined at the Mission Confirmation Review or its equivalent and documented in the "Approval to Proceed" letter from the Associate Administrator for Earth Science. Baselines may be changed only by the Associate Administrator as part of a major programmatic restructuring or reshaping activity.

External Partnerships

A wide range of U.S. Government agencies are working to understand and mitigate the effects of climate change, reduce our vulnerability to natural and technological disasters, enhance homeland and national security, stimulate our economy through technological innovation, and protect our environment. NASA is a key partner in many of these endeavors. We are a major contributor to the interagency Climate Change Science and Technology Programs. We work closely with NOAA in the U.S. Weather Research Program to improve the duration and reliability of weather forecasts. We cooperate with USGS and DOD in land cover and topographic mapping, and provide information to FEMA to improve flood plain mapping and water resources management. Further information on these interagency efforts is contained in appendix 5.

Approximately one-third of the Earth Science Enterprise budget is used to sponsor competitively-selected science, applications, and technology research grants. In this way, we assure that the best new ideas from around the Nation are brought to bear on the scientific and technical challenges reflected in our Mission. Industry plays a major role in developing our space-based and ground-based network of remote sensing, communications and computing systems. For example, the commercial remote sensing industry in the U.S. has progressed to the point where commercially owned and operated sensors are producing science-quality data and information that NASA can purchase on commercial terms. Due to this commercial partnership, NASA does not develop land remote-sensing systems with resolutions below 10 meters since such imagery is available commercially. We expect that as we pioneer space-based hyperspectral and radar technologies, these data types and other may also be available from the marketplace in the future.

Since its inception in 1958, NASA has sought out mutually beneficial cooperation with other nations and groups of nations in the peaceful application of its activities. Recognizing that Earth science is inherently international in its



scope and function and that international cooperation is critically important to our Mission, the Earth Science Enterprise currently has entered into over 290 cooperative agreements with over 60 nations in all facets of its program. Additionally, the Enterprise is an active participant in a number of Earth science-related international and multilateral forums. International participation is essential to the successful achievement of the Enterprise's goals and objectives. In order to study the various components of global change, it is necessary to gather data with a global scope in its content and reception points. It is necessary to observe phenomena that occur in different parts of the world, and this requires globally dispersed test sites, ground and air campaigns, and space-based sensors. Further, the calibration and validation of space-based observations requires regional experts and in situ data from around the world. Finally, and most importantly, scientific results are most accessible and useful to nations around the world if their scientists and assets are part of the process of discovery.

Independent Assessment and Advice

Outside the Agency, the Enterprise acquires independent evaluation and advice through two principal means. First, the Earth System Science and Applications Advisory Committee (ESSAAC) of the NASA Advisory Council advises the Enterprise on program priorities and planning. ESSAAC, along with its technology and information systems subcommittees, helps the Enterprise structure its roadmaps and assess its progress. Second, the various boards and committees of the National Research Council (NRC) advise the Enterprise on a variety of matters in science, applications, technology, and multi-program planning. The Space Studies Board and its Committee on Earth Studies are the Enterprise's primary NRC advisors who also connect the Enterprise with the committees and boards of other NRC bodies engaged in Earth science.

This striking image of the Earth emphasizes the importance of the thin layer of atmosphere that separates us from the harsh vacuum of space, and highlights the polar regions where indications of climate change are earliest and largest.

5 Beyond the Horizon

5 Beyond the Horizon: Earth System Science in the 21st Century

The grand challenge of the 21st century is to answer the question "How is the Earth changing, and what are the consequences for life on Earth?" The pathway toward the answer is a series of specific science questions concerning Earth system variability, forcings, response, consequences, and prediction. Many of these questions and our approach to answering them are discussed earlier in the Strategy. We can anticipate other questions emerging as a result of new scientific discovery and understanding.

Integrating our scientific understanding of the major components of planet Earth to achieve a holistic understanding of how it functions as a system is an essential step toward reliably predicting its future course of change. This will require concerted science and technology reserach, a strong network of partnerships, and a sustained commitment from Congress and the Executive Branch.

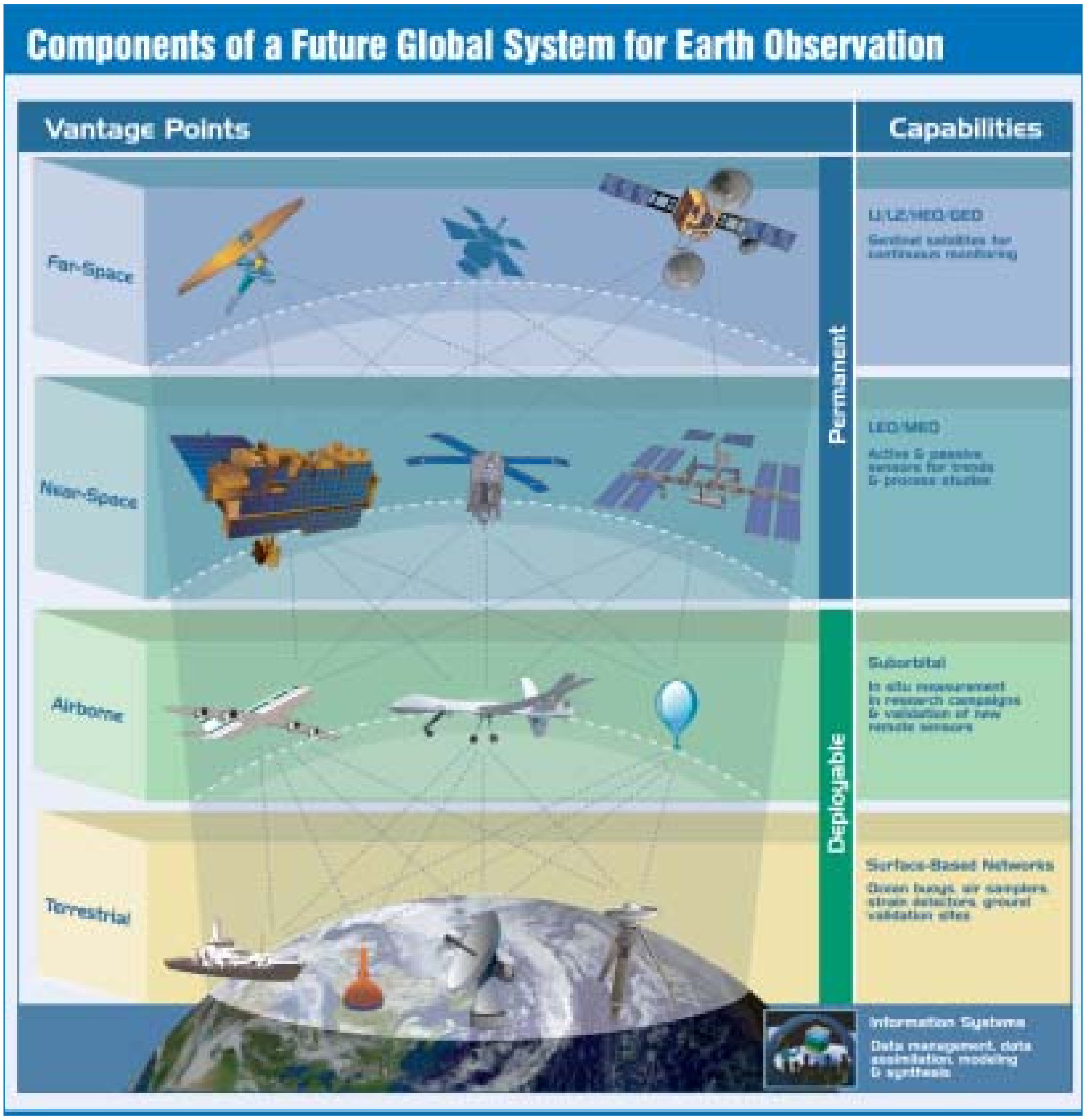
The challenge for the scientific community and NASA will be to develop—with national and international partnerships—an inclusive Earth system model suite integrating remote sensing, suborbital and in situ measurements with accurate predictive capabilities. With increasing computational capabilities, such an Earth system model suite would advance our understanding of couplings between different processes (such as those determining atmospheric composition with climate, or large-scale climate variability with weather) occurring at different spatial and temporal scales. This model suite would enable NASA and its partners to respond in the global interest in regional and local changes, and explain local and regional changes in their global context.

As we progress, the use of Earth system science information will be increasingly prevalent in our economy and society. Individuals and families will plan trips and businesses will work based on 10-day weather forecasts. Communities will prepare for hazards based on 15-month El Niño predictions, seasonal fire potential indices, and landslide and earthquake risk assessments. Agriculture and energy management will be guided by seasonal and annual precipitation and temperature forecasts and maps and other products based on NASA satellites and Earth system models. Developing regions will plan infrastructure and provide food, fiber, and fresh water more efficiently and with substantially less impact on the environment than their predecessors. The scientific knowledge we generate about the Earth system will continue to improve life on Earth.

The task for NASA's Earth Science Enterprise is to enable this future through the delivery of reliable products from a space-based observing system and through the improvement of predictive models based upon emerging scientific research. Achievement of this goal will require a sustained focus on Earth system science and the development of expanded observational capabilities. These efforts will have to be in partnership with Federal agencies having operational responsibilities and with the academic community. The alignment of measurements and scientific insights will lead to the creation of a predictive and dynamic Earth system modeling suite for all components of the Earth system—atmosphere and ocean, solid Earth, biosphere, and cryosphere. This Earth system modeling suite will serve as a decision support tool kit that enables individuals, families, business, and nations to make science-based social and policy decisions in pursuing a course to a sustainable future. Developing the comprehensive Earth system modeling suite will require close coordination with national and international partners, as well as the development of interdisciplinary and innovative scientific knowledge and technological capabilities. NASA is in a unique position to lead the development of this highly complex modeling process, especially by developing new aerospace-based architecture for observational systems that will reveal the dynamics of complex Earth systems.

Global city lights, derived from 9 months of observations from the Defense Meteorological Satellite Program, are superimposed on a darkened land surface map. Light distribution and intensity is an indicator of population and economic activity in areas of interest.

Figure 5.1



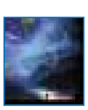
The observing and information system enabling research and applications in the 21st century will employ intelligent constellations of sensors and satellites in a variety of locations and orbits as illustrated in figure 5.1. In the future, these observing capabilities will be dynamically linked for both data fusion and for tasking the observing system itself in response to model results or sudden events such as hurricane formation or volcanic eruptions. Geographically distributed research teams and computing systems will be connected in data grids that enable collaborative modeling activities employing the vast quantities of diverse data types provided by the observing system. End users will be able to receive customized information products directly at their desktops in near-real time at no more than the cost of an international telephone call today.

Future Predictive Capabilities Enabled by Earth System Observations and Models			
Weather Forecasts	7-10 days at 90 percent	**Carbon Management**	Semi-annual, regional and site-specific assessments
Rainfall	7-day rainfall forecast routine	**Coastal Zone**	Seasonal, regional productivity; event assessment of influence discharge and disturbance effects
Winter Storms	Greater than 3 days; probabilistic guidance to 10 days		
Local Storms	7-day forecast, moderate to occasional high confidence	**Open Ocean**	Mixed-layer depth effects on productivity and fisheries
Thunderstorm Occurrence	Greater than 2-3 hours	**Coastal Zone Fisheries**	Event/seasonal nursery effects and coral reef health
Tornado Lead Time	30 minutes	**Ecosystem Forecasts**	Short-term public health risk prediction, e.g., from vector-borne disease; short-term hydrological yield for energy, floods and erosion
Flash Floods	>2-3 hours		
Hurricane Landfall	75 nautical miles at 3 days		
Hurricane Intensity	9 knots	**Invasive Species**	Early warning regionally
Air Quality	7-10 days	**Fire Forecasts**	Daily risk of fire and intensity on regional scales
Global Precipitation/ Evaporation	12 month regional rain rate	**Productivity**	Seasonal to interannual prediction of agricultural yields and carbon storage (agricultural and natural)
Longer Term Weather	1 week to 1 month with 90 percent success		
El Niño	15-20 months	**Earthquakes**	Monthly assessment of hazards at major faults
Climate Forecasts	10 years	**Volcanic Eruption**	30-60 day eruption warnings with atmospheric impacts
Sea Level Change	Accurate 10-year regional sea level		

Areas for technology investment over the next several years to enable this future vision include:

Advanced Sensors.—Remote sensing instruments that enable three-dimensional measurement of the physical , biological, chemical, and geophysical structure of the Earth's atmosphere, land and ice masses, and ocean with ultra-high spatial, spectral and temporal resolution. Examples include:

- Three-dimensional detectors
- Space-based lidar and radar constellations
- Multi-frequency radar
- Ultra-large antennas and telescopes
- Frequency agile detectors
- High frame-rate, deep well arrays
- Biological markers/sensors
- Autonomously reconfigurable sensors
- Quantum physics –based sensors
- High-performance microbolometers
- Ultra-stable detectors and optics
- High-precision calibration systems



Platforms/Architectures.—Open system architecture approaches that can seamlessly evolve as new observing and modeling approaches are developed, and to effectively manage the complex "system of systems" to be fault tolerant at system level. Examples include:

- Adaptive data management and data acquisitions
- Reconfigurable communications
- Formation-flying distributed macrostructures
- Automated calibration
- Autonomous operations
- Multi-functional structures
- Biomimetic structures
- Self-healed materials
- Nano-constructed materials
- High-accuracy independent calibration capability (multi-spacecraft, lunar, solar)

Advanced Information Systems.—Advanced information systems to enable the processing, communicating, and archiving of vast amounts of data generated by the envisioned networks of sensorcrafts, and to deliver on-demand and affordably Earth system information products to customers located anywhere and at anytime. Examples include:

- Advanced information architectures
- Reconfiguration Management
- Format Translation
- Human-computer interface for geo-spatial datasets
- Collaborative environments
- Distributed immersive visualization
- Intelligent agent
- Context sensitive adaptive processing
- High-accuracy multi-sensor and multi-platform analysis

Advanced Computing.—Advanced computing and software technology to enable the construction of complex, interdisciplinary scientific modeling systems harnessing orders of magnitude increases in computing and data management power. These new Earth system models will enable assimilation of the vast amount of data to be produced via the sensor web for now-casting, and to allow Earth system modeling to advance at the rate of scientific understanding for much improved forecasting. Examples include:

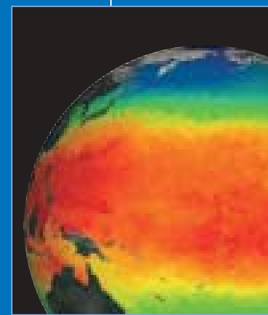
- Scientific problem solving environments
- High performance modeling and data assimilation software frameworks
- Parallel and distributed programming and computing environments
- Highly parallel and latency tolerant algorithms
- Bio-computing and quantum-computing
- High-performance hardware architectures
- High-performance on-board computing
- Supercomputer grids and super-grids

Goddard Space Flight Center's Detector Development Laboratory is a semiconductor fabrication laboratory where engineers build very sensitive detectors for ground, balloon, airplane, and satellite instruments. Detectors are like the retinas in our eyes, employed in remote sensing instruments which observe Earth, the planets, stars and galaxies. The device shown here is a programmable aperture array with a "microshutter", produced using a fabrication technique called silicon micro-machining.

The vision of an Earth System modeling suite fed by a comprehensive and collaborative global observation system and producing information employed to promote economic vitality and enable environmental stewardship begins to capture the enormous potential of Earth system science. This vision also presents enormous but exciting challenges:

- The scientific challenge of understanding the complex and dynamic Earth system
- The management challenge of mobilizing the intellectual resources needed to turn terabytes of data into megabytes of useful knowledge products
- The technological challenge of creating the integrated observing and modeling system of the future
- The systems engineering challenge of benchmarking the assimilation of Earth science observations and predictions into decision support tools for applications of national priority
- The partnership challenge of transitioning research observing capabilities of proven value into operational observing systems
- The educational challenge of training the next generation of Earth explorers

NASA's Earth Science Enterprise plays an essential leadership role in meeting these challenges and securing the scientific knowledge that will enhance the quality of life, promote economic vitality, and equip us to understand and protect our home planet for this and future generations.



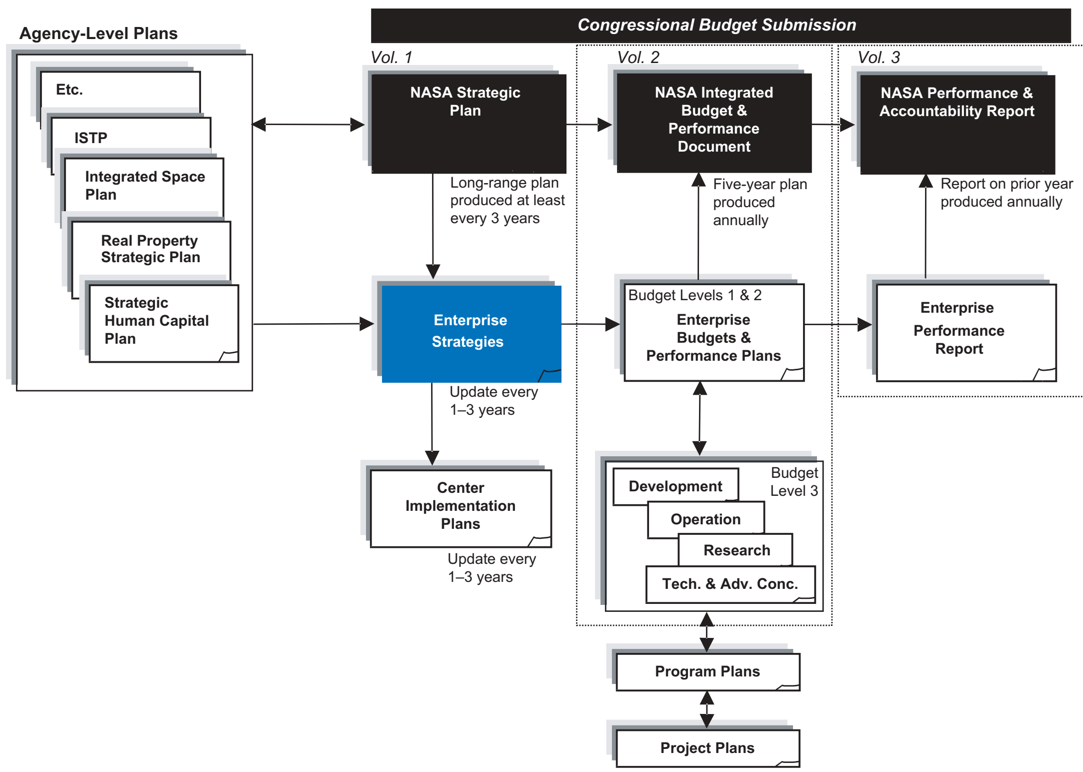
Appendices

Appendix 1

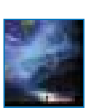
Relationship to Agency Planning

The Agency's planning process includes the development of a Strategic Plan, the annual budget, and a performance plan. The Strategic Plan is a 5-year plan, updated every 3 years, that defines the Agency's goals and objectives. The NASA Enterprises base their planning on the strategic emphasis, implementing strategies, goals, and objectives outlined in the Strategic Plan. In addition, Enterprise budget planning and performance reporting are directly traceable to the Agency-level documents.

The Enterprise Strategy communicates the results of the Agency and Enterprise planning processes to the NASA stakeholders and other audiences listed below.



Stakeholder/Audience	Enterprise Strategy Function
Executive and Legislative Branches	Communicate purpose and value of investments
NASA Employees	Achieve alignment within the Enterprise and Agency
Other NASA Enterprises	Strengthen inter-Enterprise collaboration
Science Community	Document consensus on objectives and priorities
Contractor Community	Communicate programmatic objectives and priorities
Interagency, International, and Commercial Partners	Establish basis for future collaborations
The Public	Inform and inspire



Appendix 2

Principal Enterprise Partnerships

Space Flight Enterprise

- Functional and operational requirements for new technologies
- Spaceport launch facilities
- Integrate payloads
- Conduct experiments on the Space Shuttle and on the ISS
- Service space telescopes
- Launch robotic spacecraft on expendable launch vehicles
- Rocket propulsion testing
- Communications and data services
- Education and public outreach programs

Aerospace Technology Enterprise

- Advanced technology development and transfer
- Aerospace Technology Enterprise assets
- Systems analysis capabilities
- Technology problem-solving expertise
- Commercial technology transfer to Enterprises
- Orbital Space Plane
- Airborne sciences
- Education and public outreach programs

Space Science Enterprise

- Functional and operational requirements for new technologies
- Functional and operational requirements for launch vehicles
- Manage Deep Space Network
- Manage optical communications development
- Manage Astrobiology Program
- Provide space weather data
- Education and public outreach programs

Biological and Physical Research Enterprise

- Functional and operational requirements for new technologies
- Functional and operational requirements for launch vehicles and ISS
- Biomedical research
- Operational protocols
- Physical science design and safety standards
- Data measurement for Mars related to sustainable human presence and safety
- Education and public outreach programs

Earth Science Enterprise

- Functional and operational requirements for new technologies
- Functional and operational requirements for launch vehicles
- Study of Sun-Earth connection
- Adapt Earth system models to other planets
- Assist in improving aviation safety
- Study effects of global change on human health
- Ground network services
- Education and public outreach programs

Education Enterprise

- Guidance and integration of other Enterprises' education programs
- Linkages of NASA education programs to other Enterprises' future competencies and skill requirements
- Public outreach programs

Key

- Supports Space Flight Enterprise
- Supports Aerospace Technology Enterprise
- Supports Space Science Enterprise
- Supports Biological and Physical Research Enterprise
- Supports Earth Science Enterprise
- Supports Education Enterprise

Appendix 3

Delivering on Our Commitments

Commitments in the 2000 Earth Science Enterprise Strategic Plan	Results Achieved
Science	
Establish a benchmark for global rainfall	Reduced uncertainty in global tropical rainfall by a factor of 2 via TRMM (launched in 1997)
Estimate uptake of CO2 from global measurements of the terrestrial biosphere	Produced a three year continuous record of biosphere/atmosphere interaction (SeaWiFS in 1997)
Provide precise global measurements of atmospheric temperature and humidity	Initiated a climate-quality data record (Aqua in 2001)
Make global measurements of cloud properties to determine Earth's response to solar radiation	Initiated a climate-quality data record (Terra in 1999 and Aqua in 2001
Measure global winds and topography to improve accuracy and length of weather prediction and drive models of ocean impacts on climate change	Demonstrated the ability to predict severe storms over the ocean 48 hours in advance. (QuikSCAT in 1999 and SeaWinds in 2002 for winds and Jason-1 in 2001 for topography). Both data sets are being used by NOAA for operational weather prediction;
Produce 3-D maps of the entire inhabited surface of the Earth	Produced the first globally consistent topographic data set at 90m (SRTM in 2000)
Applications and Education	
Demonstrate applications of geospatial data to agriculture, forestry, urban & transportation planning, etc.	USDA, USFS, DOT and others are using Landsat and MODIS data in their applications. An example is the MODIS Rapid Response system for fire monitoring, which provides information to USFS for fire damage assessment. 12 national applications identified as priorities with partner Federal agencies.
Expand use of commercial systems in providing remote sensing data for research	Provisions for using commercial data are included in all ESE research solicitations
Collaborate with educators to develop new curricula support materials using Earth science data and discoveries	Education product review process uses teachers to assess and provide feedback on products proposed for educational use. Workshops held to train teachers in the use of approved products.
Technology	
Implement satellite formation flying to improve science return; New Millennium Program to space-validate revolutionary technologies	Demonstrated the first space-based constellation of Earth observing satellites (land imaging satellites Terra, Landsat 7, SAC-C and EO-1 flying in formation; second set for atmospheric observation (Aqua, Aura, Cloudsat Calipso)

Commitments in the 2000 Earth Science Enterprise Strategic Plan	Results Achieved
Technology—continued	
Explore new instrument concepts for next decade science missions	Demonstrated nine new technologies for use in future satellites (EO-1). New instruments developed in the Instrument Incubator Program were used in four of six Earth System Science Pathfinder mission concepts.
Employ high-end supercomputers to address Earth system modeling challenges	Achieved a ten-fold improvement in climate simulation run time through a partnership between NASA and Silicon Graphics, Inc..
Collaborate with operational agencies in mission planning, development, and utilization	Initiated several major space-based missions with operational agency partners, e.g., NASA, NOAA, and DOD are collaborating in the NPOESS Preparatory Project mission; NASA and USGS are collaborating in the Landsat Data Continuity Mission commercial data purchase; NASA and CNES are partnering with NOAA and EUMETSAT in the Jason follow-on ocean topography mission

Appendix 4

Earth Science Questions

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

(1) How is the global Earth system changing? (Variability)

(a) How are global precipitation, evaporation, and the cycling of water changing?
(b) How is the global ocean circulation varying on interannual, decadal, and longer time scales?
(c) How are global ecosystems changing?
(d) How is atmospheric composition changing?
(e) What changes are occurring in the mass of the Earth's ice cover?
(f) How is the Earth's surface being transformed by naturally-occurring tectonic and climatic processes?

(2) What are the primary forcings of the Earth system? (Forcing)

(a) What trends in atmospheric constituents and solar radiation are driving global climate?
(b) What changes are occurring in global land cover and land use, and what are their causes?
(c) What are the motions of the Earth's interior, and how do they directly impact our environment?

(3) How does the Earth system respond to natural and human-induced changes? (Response)

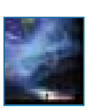
(a) What are the effects of clouds and surface hydrologic processes on Earth's climate?
(b) How do ecosystems, land cover and biogeochemical cycles respond to and affect global environmental change?
(c) How can climate variations induce changes in the global ocean circulation?
(d) How do atmospheric trace constituents respond to and affect global environmental change?
(e) How is global sea level affected by natural variability and human-induced change in the Earth system?

(4) What are the consequences of change in the Earth system for human civilization? (Consequences)

(a) How are variations in local weather, precipitation and water resources related to global climate variation?
(b) What are the consequences of land cover and land use change for human societies and the sustainability of ecosystems?
(c) What are the consequences of climate change and increased human activities for coastal regions?
(d) What are the effects of global atmospheric chemical and climate changes on regional air quality?

(5) How will the Earth system change in the future and how can we improve predictions through advances in remote sensing observations, data assimilation and modeling? (Prediction)

(a) How can weather forecast duration and reliability be improved?
(b) How can predictions of climate variability and change be improved?
(c) How will future changes in atmospheric composition affect ozone, climate, and global air quality?
(d) How will carbon cycle dynamics and terrestrial and marine ecosystems change in the future?
(e) How will water cycle dynamics change in the future?
(f) How can our knowledge of Earth surface change be used to predict and mitigate natural hazards?



Appendix 5

NASA's Earth Science Enterprise Role in U.S. Climate Change Science and Technology Programs

In February 2002, the President created a new Cabinet-level management structure, the Committee on Climate Change Science and Technology Integration, to oversee the full scope of federal climate change research and technology development. Within this structure, the Climate Change Science Program (CCSP) integrates research and related activities sponsored by the U.S. Departments of Agriculture, Commerce, Defense, Energy, Health and Human Services, Interior, State, and Transportation, as well as the Environmental Protection Agency, NASA, the National Science Foundation, Smithsonian Institution, U.S. Agency for International Development, Office of Science and Technology Policy, and Office of Management and Budget.

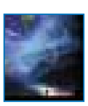
The Director of the Climate Change Science Program Office (CCSPO) is the Assistant Secretary of Commerce for Oceans and Atmosphere. The CCSP encompasses the Climate Change Research Initiative and the U.S. Global Change Research Program. The CCSPO has produced a vision document and strategic plan that can be accessed at *http://www.climatescience.gov*. NASA's Earth system science research paradigm, science focus areas, and program elements are well aligned with those of the CCSP.

CCSP Research Goals	Earth Science Enterprise Research Questions
Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change	How is the global Earth system changing? (Variability)
Improve quantification of the forces bringing about changes in the Earth's climate and related systems	What are the primary causes of change in the Earth system? (Forcings)
Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future	How does the Earth system respond to natural and human-induced changes? (Response)
Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes	What are the consequences of change in the Earth system for human civilization? (Consequences)
Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change	How will the Earth system change in the future? (Prediction)

CCSP Core Approaches	Earth Science Enterprise Program Elements
Scientific Research	Research
Observations (and Data Management)	Observations and Information Systems
Decision Support	Applications
	Advanced Technology
Communications	Education

CCSP Research Elements	Earth Science Enterprise Science Focus Areas
Atmospheric Composition	Atmospheric Composition
Climate Variability and Change	Climate Variability and Change
Global Water Cycle	Global Water and Energy Cycle
Land Use / Land Cover Change Global Carbon Cycle Ecosystems	Carbon Cycle and Ecosystems
Human Contributions and Responses	
	Weather
	Earth Surface and Interior

The Climate Change Technology Program (CCTP) is established within the Department of Energy, and includes the same member agencies as the CCSP (with the exception of the Smithsonian Institution). The CCTP is build upon six interagency working groups. NASA chairs the Measurement and Monitoring Working Group.



Appendix 6

List of Acronyms

AIST	Advanced Information Systems Technology
ARC	NASA Ames Research Center
AT	Aerospace Technology Enterprise
ATI	Advanced Technology Initiative
AWIN	Aviation Weather Information Network
CALIPSO	Cloud Aerosol Lidar Infrared Pathfinder Satellite Observations
CADRE	Crop Assessment Data Retrieval and Evaluation
CCSP	Climate Change Science Program
CCSPO	Climate Change Science Program Office
CCTP	Climate Change Technology Program
CDC	Centers for Disease Control
CINDI	Center for Integration of Natural Disaster Information
CNES	Centre Nationale d'Etudes Spatiale (French Space Agency)
CT	Computational Technology
DHS	Department of Homeland Security
DIAL	differential absorption lidar
DLESE	Digital Library for Earth System Education
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOT	Department of Transportation
DFRC	NASA Dryden Flight Research Center
EOS	Earth Observing System
EOSDIS	Earth Observing System Data and Information System
EPA	Environmental Protection Agency
ESIPs	Earth Science Information Partners
ESMF	Earth System Modeling Framework
ESSAAC	Earth System Science and Applications Advisory Committee
ESSP	Earth System Science Pathfinder
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAA	Federal Aviation Administration

FEMA	Federal Emergency Management Agency
GEO	geostationary Earth orbit
GLOBE	Global Learning and Observations for a Better Environment
GPM	Global Precipitation Measurement
GOES	Geostationary Operational Environmental Satellites
GPS	Global Positioning System
GSFC	NASA Goddard Space Flight Center
GRACE	Gravity Recovery And Climate Experiment
HAZUS	standardized, national methodology for assessing losses from natural hazards
HEO	highlyelliptical orbit
HYDROS	Hydrosphere State Mission
IIP	Instrument Incubator Program
InSAR	Interferometric Synthetic Aperature Radar
LaRC	NASA Langley Research Center
JCSDA	Joint Center for Satellite Data Assimilation
LEO	low-altitude Earth-orbit
JPL	Jet Propulsion Laboratory
MEO	medium-Earth orbit
MISR	Multi-angle Imaging SpectroRadiometer
MODIS	Moderate Resolution Imaging Spectroradiometer
MSLP	mean sea level pressure
MSMT	Mission and Science Measurement Technology
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Prediction
NEMA	National Emergency Management Agency
NIH	National Institutes of Health
NMP	New Millennium Program
NOPP	National Ocean Partnership Program
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NPP-Bridge	NPOESS Preparatory Project
NRC	National Research Center
NRCan	Natural Resources Canada

NSF	National Science Foundation
NSGIC	National States Geographic Information Council
OCO	Orbiting Carbon Observatory
OMB	Office of Management and Budget
OSIRIS	Ocean salinity Soil moisture Integrated Radiometer-radar Imaging System
POES	Polar-orbiting Operational Environmental Satellites
PNAS	Proceedings of the National Academy of Sciences
QuikSCAT	Quick Scatterometer
REASoN	Research, Education, and Application Solutions Network
SAGE	Stratospheric Aerosal and Gas Experiment
SBIR	Small Business Innovation Research
SEARCH	Study of Environmental Arctic Change
SEC	Sun-Earth Connections
SEDAC	Socioeconomic Data Archive Center
SIPs	State Implementation Plans
SLR	satellite laser ranging
SORCE	Solar Radiation and Climate Experiment
SPoRT	Short-term Prediction Research and Transition Center
SRTM	Shuttle Radar Topography Mission
SSC	Stennis Space Center
SVS	Synthetic Vision System
TOMS	Total Ozone Mapping Spectrometer
TRMM	Tropical Rainfall Measuring Mission
USAID	U.S. Agency for International Development
USBoR	U.S. Bureau of Reclamation
USDA	U.S. Department of Agriculture
USFS	USDA Forest Service
USGS	U.S. Geological Survey
USWRP	U.S. Weather Research Program
VBLI	Very Long Base Interferometry

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