National Aeronautics and
Space Administration

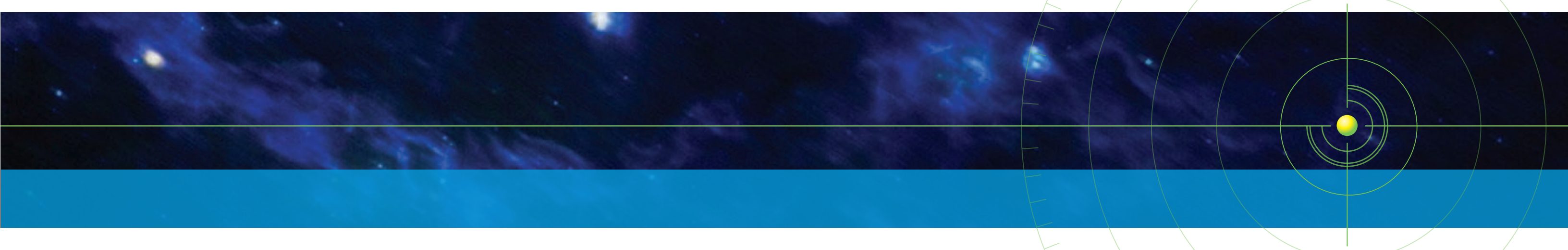
Earth Science
Technology Plan 2004

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.



Earth Science Technology Plan 2004

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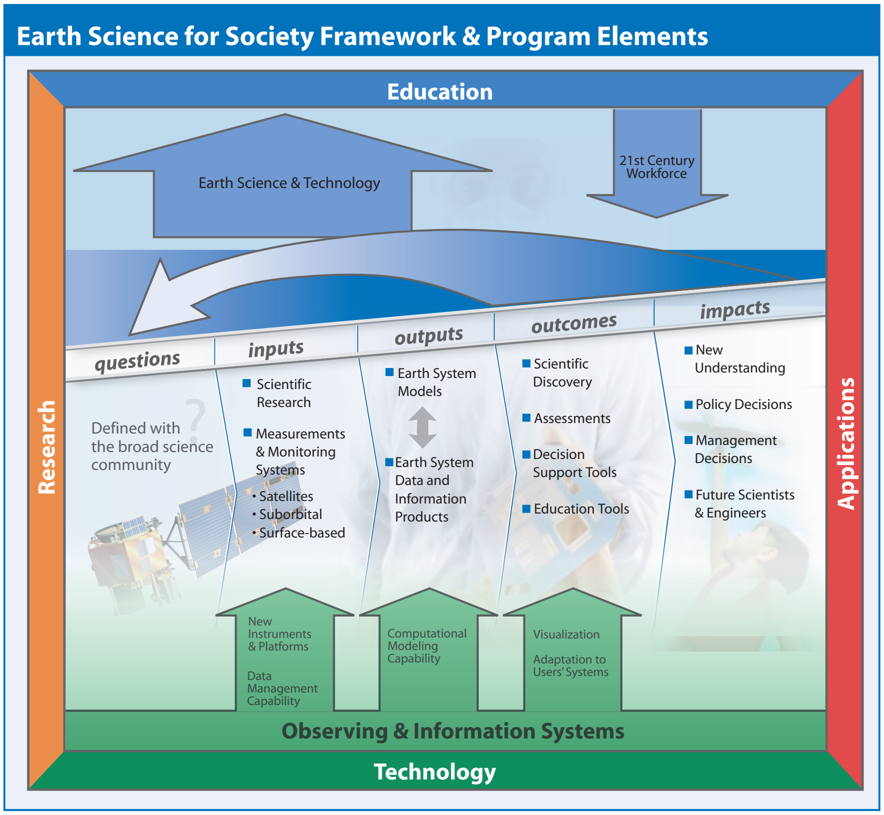
1.0 Advanced Technology for ES

1.1 The Earth Science Mission

The mission of the Earth-Sun System Division (the Division) of NASA's Science Mission Directorate is to understand and protect our home planet by using a view from space to study the Earth-Sun system and improve predictions of Earth-system change. The Division's science and applications programs pursue the long-term goal of understanding Earth and its environment as a global system, with the concomitant ability of applying this knowledge for predicting the future behavior of our global ecosystem. NASA has a distinctive role in this national endeavor because it employs the unique vantage point of space to provide information that is obtainable in no other way. Our research programs study the interactions between the atmosphere, oceans, continents, and life to increase our knowledge of the Earth's system with an emphasis on understanding global-climate change.



*The basic **science for society** framework is shown with the four major elements required to achieve Division objectives in the perimeter. The strategic approach to implementation of these four elements is described in NASA's Earth Science Strategy Document.*

The Division conducts four basic activities including a **research** program to increase our knowledge of the Earth system, an **applications** program to demonstrate practical use of Earth-system information for planners and decision-makers in government; business; and the public, and a **technology** program to enable new capabilities for future study of the Earth system. NASA's unique capabilities in space-based and suborbital observing systems, information systems, global modeling, and decision-support systems integration combine to provide continuing advances in these three areas. Also, the Division conducts an **education** program that shares the discoveries and knowledge gained from Division programs with the public to enhance science; mathematics; and technology education, and to inspire future generations of Americans.

The Division has a supporting role in NASA's mission to explore the universe and to search for life. Earth Science (ES) research and knowledge of Earth's processes provide a model for the study and understanding of other planets. In this arena, the Division has developed unique capabilities for the design and development of systems that conduct remote and in-situ observations; support data analysis and management; and perform numerical modeling of planetary processes, and these capabilities serve as precursors for those to be deployed elsewhere in the solar system.

1.2 Role of the Technology Program

Technology plays a major role in shaping the fundamental ES research and applied capabilities of the future. Advanced technologies make possible space-based measurements that provide greater insight into how the Earth system works. Additionally, these technologies contribute to terrestrial applications that benefit the public; industry; and government, thus serving our national interests well. Sustained technology advancements support Division goals on two crucial areas:

- They enable previously unforeseen or unfeasible science investigations; and,
- They enhance existing measurement capabilities by reducing their cost, risk, or development times.

The Division's Technology Program (the Program) was established in response to a 1997 ES Biannual Review to ensure that a continuous, well-focused effort addresses crucial Division technology needs while maximizing return on investment of technology dollars. The goal of the Program is to ***foster the creation and infusion of new technologies into Earth-science missions.***

This document outlines the planning and implementation guidelines we have established to meet the goal of developing technology investments that best support Division objectives. The **Earth Science Technology Plan 2004** is an extension of the Earth-Sun System's Strategic Plan and will be updated as research priorities, program needs, and the overall technology program evolves.

The powers of remote sensing and computer visualization technologies combine to allow views of Earth that are otherwise impossible to obtain. This image of the Earth disk over Antarctica is a composite of data from several generations of remote sensing satellites. AVHRR data was used for the land, SeaWiFS data for the oceans, and the clouds are a combination of TERRA's MODIS images over the poles and NOAA weather satellite data for the mid and low latitudes.

Image credit: Marit Jentoft-Nilsen, NASA/GSFC Image Visualization Laboratory. Using data from NASA and NOAA satellites.

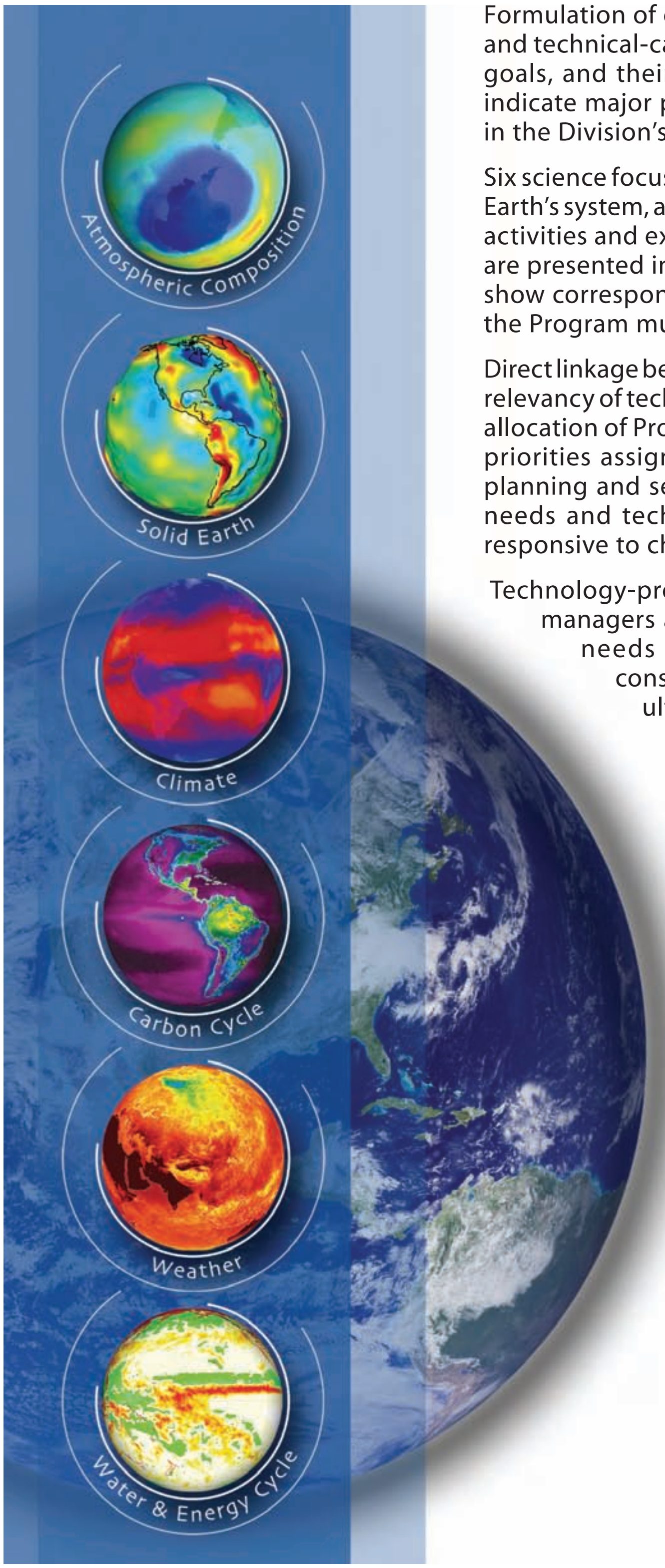
2.0 Program Drivers and Priorities

Formulation of our technology portfolio is driven by the research goals and technical-capability needs of the Division's science program. These goals, and their assigned priorities, are articulated as roadmaps that indicate major program activities for the **science focus areas** outlined in the Division's Science Plan.

Six science focus areas were established to address major components of Earth's system, and their respective roadmaps illustrate proposed research activities and expected products for each of the areas. These roadmaps are presented in the following pages along with traceability tables that show corresponding measurement goals and key technical capabilities the Program must deliver to enable roadmap activities.

Direct linkage between technology products and focus-area needs ensures relevancy of technologies in the investment portfolio and helps guide the allocation of Program resources. Equally important, this linkage conveys priorities assigned to science focus-area activities to the technology planning and selection process. The one-to-one traceability between needs and technology products ensures that the Program remains responsive to changes in the Division's strategy and program plans.

Technology-program managers work closely with Division focus-area managers and the science community to characterize technology needs and to identify technology options that deserve consideration for inclusion in the focus-area roadmaps, and ultimately, in the Program's portfolio. These collaborations are conducted through open community workshops, and are supported by system studies that provide technical information needed to evaluate the merits of alternative technology options.



Shown are respective views of our planet's environment obtained from focus-area measurements. These focus areas are used to identify research questions to be addressed and to define effective strategies to pursue answers to those questions.

2.1 Technology Advancement Areas

A variety of remote-sensing technologies are available to obtain ES measurements with both terrestrial and space-based instrumentation. Table 1 illustrates how these technologies provide capabilities useful across several of the science focus areas. The Program promotes development of such technologies with an emphasis on providing new capabilities that advance research goals indicated by the focus-area roadmaps.

Science Focus Areas						
Atmospheric Composition	Solid Earth	Climate	Carbon Cycle	Weather	Water & Energy Cycle	**Remote Sensing Technologies**
	●	●			●	Advanced grating spectrometer
	●	●			●	Advanced broadband spectrometer
●	●	●	●		●	Advanced imaging spectrometry
●				●	●	Advanced microwave sounder
●	●	●	●	●	●	In-space multi-frequency lidar
●	●			●	●	In-space diff. absorption lidar (DIAL)
●	●	●		●	●	In-space Doppler lidar
●	●		●		●	Multi-angle imaging spectroradiometry
	●	●			●	Advanced radar and laser altimetry
●	●		●		●	Advanced thermal radiometry
●	●	●		●	●	Advanced microwave radiometry
		●		●	●	Large aperture antenna radiometry
		●	●		●	Interferometric synth. aperture radar
	●	●		●	●	Advanced scatterometry
		●	●	●		Large, lightweight antennas
●	●		●			Advanced hyperspectral radiometry
	●					Laser interferometry
	●				●	Quantum gravity gradiometer
						Computing & Communications Technologies
●	●	●	●	●	●	Standards and interface protocols
●	●	●	●	●	●	Data mining, and data fusion
●	●	●	●	●	●	High, sustained comp. throughput
●	●	●	●	●	●	High volume data management
●	●	●	●	●	●	Data visualization
●	●	●	●	●	●	Onboard data processing
●	●	●	●	●	●	Data grids

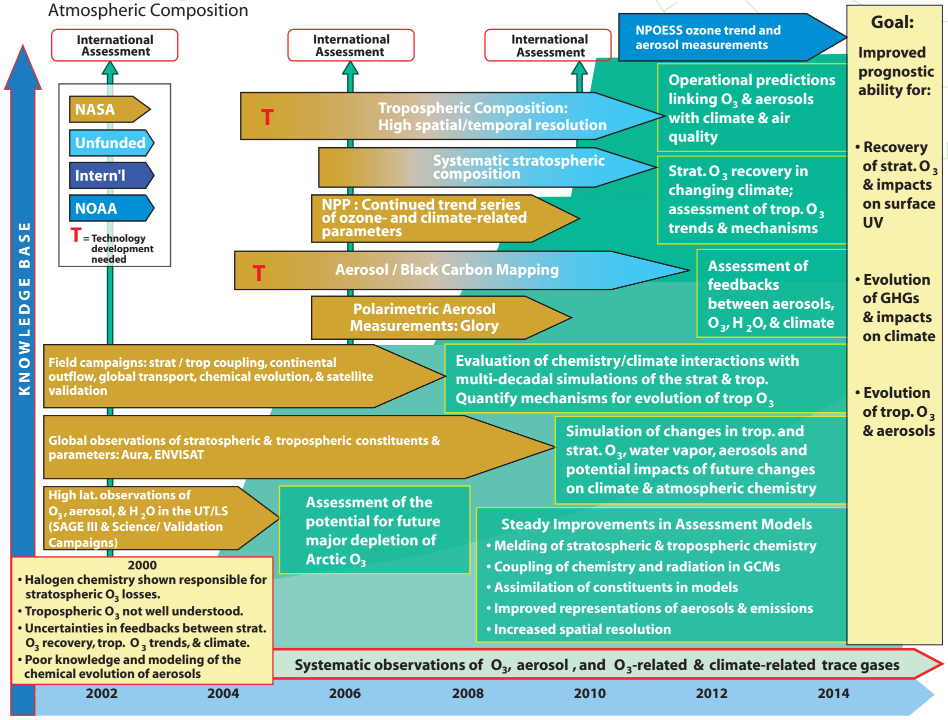
Table 1: Remote sensing, computing, and communications technologies play a crucial role for the science program focus areas. Sustained technology developments are needed to provide future remote-sensing improvements and new capabilities that support advanced Earth-science research activities.

2.2 Technology Roadmaps

Roadmaps included in the following pages were prepared in support of NASA's 2004 budget. They should not be regarded as final, but rather, as 'living documents' that will evolve in response to scientific and programmatic developments.

RoadMap

Atmospheric Composition



Technology Table

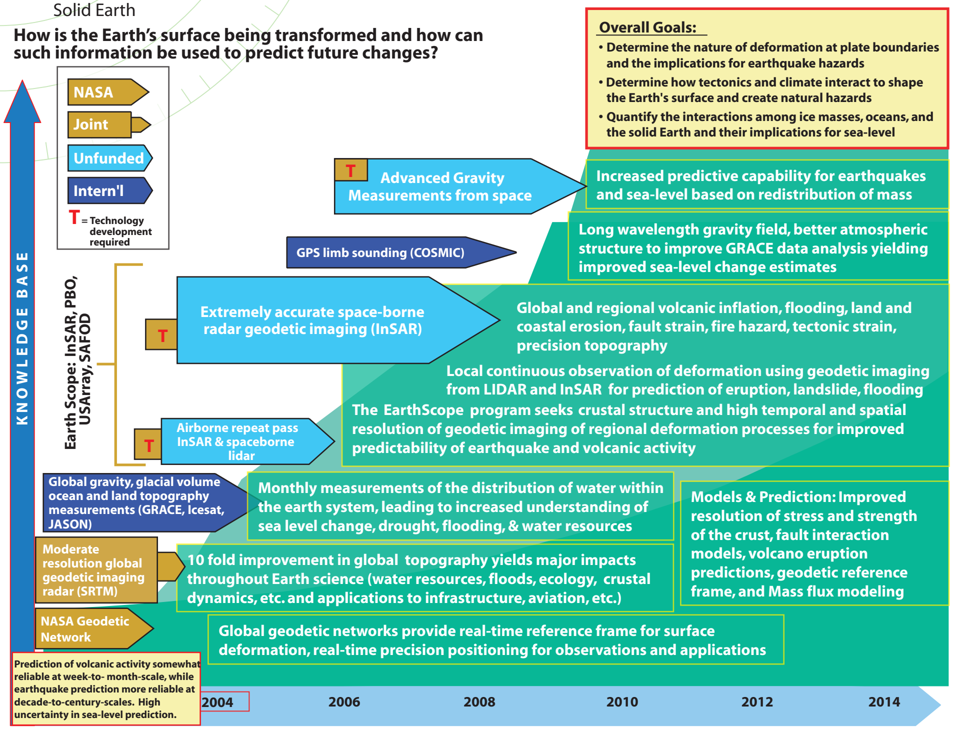
Atmospheric Composition

SCIENCE MEASUREMENT	TECHNOLOGY OPTIONS	CHALLENGES
Tropospheric Composition: High Spatial/ Temporal Resolution Products	Hyperspectral Interferometer/Spectrometer	2200-2500 nm Channel (HgCdTe arrays)
	Multiangle Spectropolarimeter	1-100 kHz Charge-caching Detector Arrays
	Fabry-Perot Interferometer	High-sensitivity Uncooled FPA's
	High Spectral/Spatial Resolution IR Sounder	0.6 km Spacial Resolution, WFOV Pushbroom Imaging, NEdt = 0.1-0.3K
	UV-NIR Multispectral Polarimetric Lidar	High Efficiency, kHz-PRF, 1064/532/355 nm Laser
	High Spectral Resolution Lidar	800 Hz, 0.05pm, 40W Laser
	Trace Gas DIAL	.5 - 2J/20-100Hz/UV – NIR Lasers
Systematic Stratospheric Composition	Advanced Microwave Sounder	Deployable (~5m) Precision (~10m) Antenna
	Micro-FTS	Constellation of Micro-FTS Limb Sounders
Aerosol/Black Carbon Mapping	Multi-angle Spectropolarimeter	1-100 kHz Charge-caching Detector Arrays
	UV-NIR Multispectral Polarimetric Lidar	High Efficiency, kHz-PRF, 1064/532/355 nm Laser
	High Spectral Resolution Lidar	800 Hz, 0.05 pm, 40 W Laser
	Wide-Field Imaging Spectrometer	>120 deg. FOV; 360-800 nm

RoadMap

Solid Earth

How is the Earth's surface being transformed and how can such information be used to predict future changes?



Overall Goals:

- Determine the nature of deformation at plate boundaries and the implications for earthquake hazards
- Determine how tectonics and climate interact to shape the Earth's surface and create natural hazards
- Quantify the interactions among ice masses, oceans, and the solid Earth and their implications for sea-level

NASA

Joint

Unfunded

Intern'l

T = Technology development required

KNOWLEDGE BASE

Earth Scope: InSAR, PBO, USArray, SAFOD

T Advanced Gravity Measurements from space

Increased predictive capability for earthquakes and sea-level based on redistribution of mass

GPS limb sounding (COSMIC)

Long wavelength gravity field, better atmospheric structure to improve GRACE data analysis yielding improved sea-level change estimates

T Extremely accurate space-borne radar geodetic imaging (InSAR)

Global and regional volcanic inflation, flooding, land and coastal erosion, fault strain, fire hazard, tectonic strain, precision topography

Local continuous observation of deformation using geodetic imaging from LIDAR and InSAR for prediction of eruption, landslide, flooding

T Airborne repeat pass InSAR & spaceborne lidar

The EarthScope program seeks crustal structure and high temporal and spatial resolution of geodetic imaging of regional deformation processes for improved predictability of earthquake and volcanic activity

Global gravity, glacial volume ocean and land topography measurements (GRACE, Icesat, JASON)

Monthly measurements of the distribution of water within the earth system, leading to increased understanding of sea level change, drought, flooding, & water resources

Models & Prediction: Improved resolution of stress and strength of the crust, fault interaction models, volcano eruption predictions, geodetic reference frame, and Mass flux modeling

Moderate resolution global geodetic imaging radar (SRTM)

10 fold improvement in global topography yields major impacts throughout Earth science (water resources, floods, ecology, crustal dynamics, etc. and applications to infrastructure, aviation, etc.)

NASA Geodetic Network

Global geodetic networks provide real-time reference frame for surface deformation, real-time precision positioning for observations and applications

Prediction of volcanic activity somewhat reliable at week-to- month-scale, while earthquake prediction more reliable at decade-to-century-scales. High uncertainty in sea-level prediction.

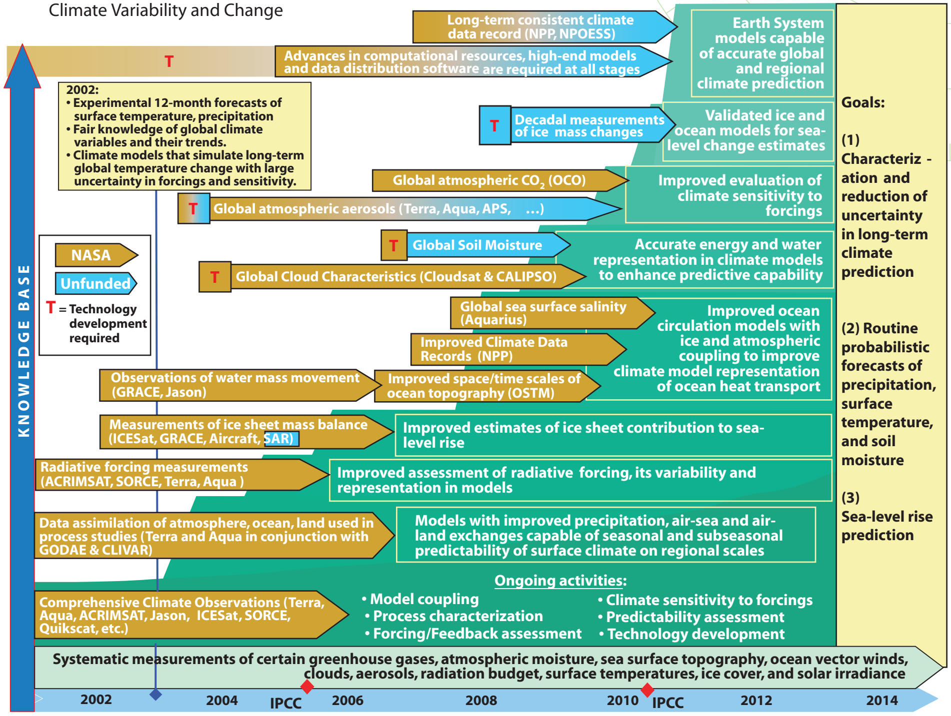
Technology Table

Solid Earth

	SCIENCE MEASUREMENT	TECHNOLOGY OPTIONS	CHALLENGES
SURFACE DEFORMATION & STRESS	Advanced Gravity Measurements from Space	Laser Interferometer Quantum Gravity Gradiometer	Micro-thrusters adjust spacecraft to test mass to within 1 nanometer rms over 100 seconds Laser frequency stabilization: 1.E-15 rms,100 sec High flux (> 10^10/s) atom source Gradiometer 1-axis measurements with accuracy <~10^(-15) m/s/s/m rms
	Airborne Repeat-Pass InSAR	UAV Repeat-Pass SAR	L-band electronically scanning arrays: 2m x 0.5m Low mass (<50kg) low power (DC<100W) modular/reconfigurable radar electronics Stability of the baseline to within a 10m tube
LAND SURFACE TOPOGRAPHY	Spaceborne Lidar	Imaging Lidar Scanning Laser Altimeter	Laser pulse width <1 nanosecond Wall plug efficiency >3% Waveform digitizer pulse rates >100 kHz Laser transmitters: 75 kHz rep-rate, 5 nsec pulsewidths, and 0.1 mJ pulse energy
	Extremely Accurate Space-borne Radar Geodetic Imaging	LEO L-band InSAR MEO L-band InSAR GEO L-band InSAR	Lightweight deployable radar antenna: 3 x 15m 10-30W T/R modules with high efficiency (>60%) Tropospheric correction Real-time onboard processors and algorithms Lightweight deployable radar antenna: 10 x 40m, 30m diameter circular

RoadMap

Climate Variability and Change



KNOWLEDGE BASE

T

Long-term consistent climate data record (NPP, NPOESS)

Advances in computational resources, high-end models and data distribution software are required at all stages

2002:
- Experimental 12-month forecasts of surface temperature, 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.

NASA

Unfunded

T = Technology development required

T Decadal measurements of ice mass changes

Global atmospheric CO_2 (OCO)

T Global atmospheric aerosols (Terra, Aqua, APS, …)

T Global Soil Moisture

T Global Cloud Characteristics (Cloudsat & CALIPSO)

Global sea surface salinity (Aquarius)

Improved Climate Data Records (NPP)

Observations of water mass movement (GRACE, Jason)

Improved space/time scales of ocean topography (OSTM)

Measurements of ice sheet mass balance (ICESat, GRACE, Aircraft, SAR)

Radiative forcing measurements (ACRIMSAT, SORCE, Terra, Aqua)

Data assimilation of atmosphere, ocean, land used in process studies (Terra and Aqua in conjunction with GODAE & CLIVAR)

Comprehensive Climate Observations (Terra, Aqua, ACRIMSAT, Jason, ICESat, SORCE, Quikscat, etc.)

Earth System models capable of accurate global and regional climate prediction

Validated ice and ocean models for sea-level change estimates

Improved evaluation of climate sensitivity to forcings

Accurate energy and water representation in climate models to enhance predictive capability

Improved ocean circulation models with ice and atmospheric coupling to improve climate model representation of ocean heat transport

Improved estimates of ice sheet contribution to sea-level rise

Improved assessment of radiative forcing, its variability and representation in models

Models with improved precipitation, air-sea and air-land exchanges capable of seasonal and subseasonal predictability of surface climate on regional scales

Ongoing activities:
- Model coupling
- Process characterization
- Forcing/Feedback assessment
- Climate sensitivity to forcings
- Predictability assessment
- Technology development

Systematic measurements of certain greenhouse gases, atmospheric moisture, sea surface topography, ocean vector winds, clouds, aerosols, radiation budget, surface temperatures, ice cover, and solar irradiance

Goals:

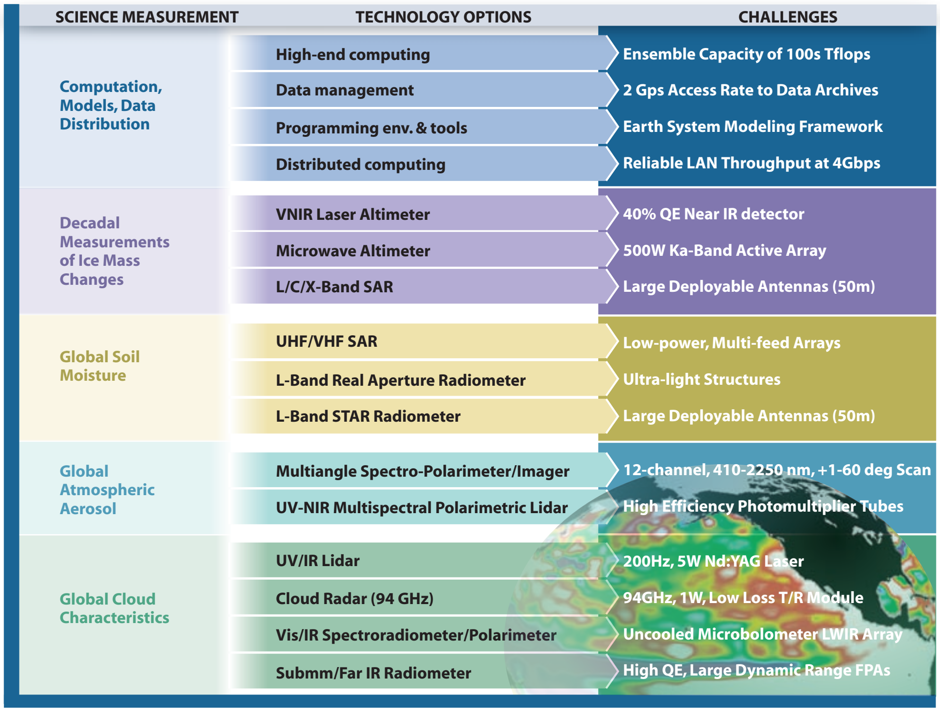
(1) Characterization and reduction of uncertainty in long-term climate prediction

(2) Routine probabilistic forecasts of precipitation, surface temperature, and soil moisture

(3) Sea-level rise prediction

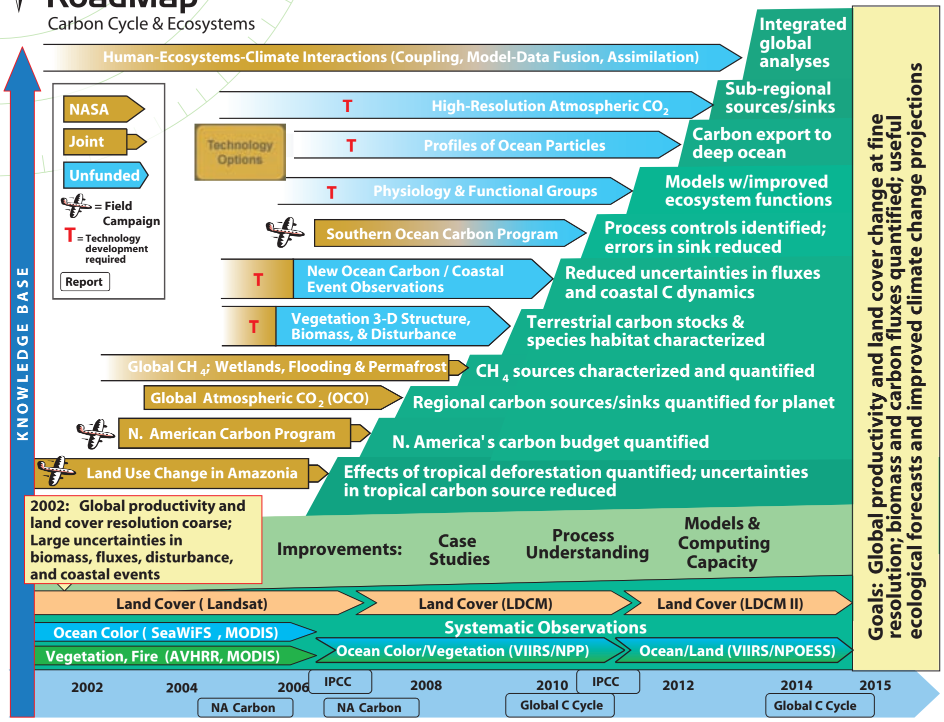
Technology Table

Climate Variability and Change



SCIENCE MEASUREMENT	TECHNOLOGY OPTIONS	CHALLENGES
Computation, Models, Data Distribution	High-end computing	Ensemble Capacity of 100s Tflops
	Data management	2 Gps Access Rate to Data Archives
	Programming env. & tools	Earth System Modeling Framework
	Distributed computing	Reliable LAN Throughput at 4Gbps
Decadal Measurements of Ice Mass Changes	VNIR Laser Altimeter	40% QE Near IR detector
	Microwave Altimeter	500W Ka-Band Active Array
	L/C/X-Band SAR	Large Deployable Antennas (50m)
Global Soil Moisture	UHF/VHF SAR	Low-power, Multi-feed Arrays
	L-Band Real Aperture Radiometer	Ultra-light Structures
	L-Band STAR Radiometer	Large Deployable Antennas (50m)
Global Atmospheric Aerosol	Multiangle Spectro-Polarimeter/Imager	12-channel, 410-2250 nm, +1-60 deg Scan
	UV-NIR Multispectral Polarimetric Lidar	High Efficiency Photomultiplier Tubes
Global Cloud Characteristics	UV/IR Lidar	200Hz, 5W Nd:YAG Laser
	Cloud Radar (94 GHz)	94GHz, 1W, Low Loss T/R Module
	Vis/IR Spectroradiometer/Polarimeter	Uncooled Microbolometer LWIR Array
	Submm/Far IR Radiometer	High QE, Large Dynamic Range FPAs

RoadMap
Carbon Cycle & Ecosystems



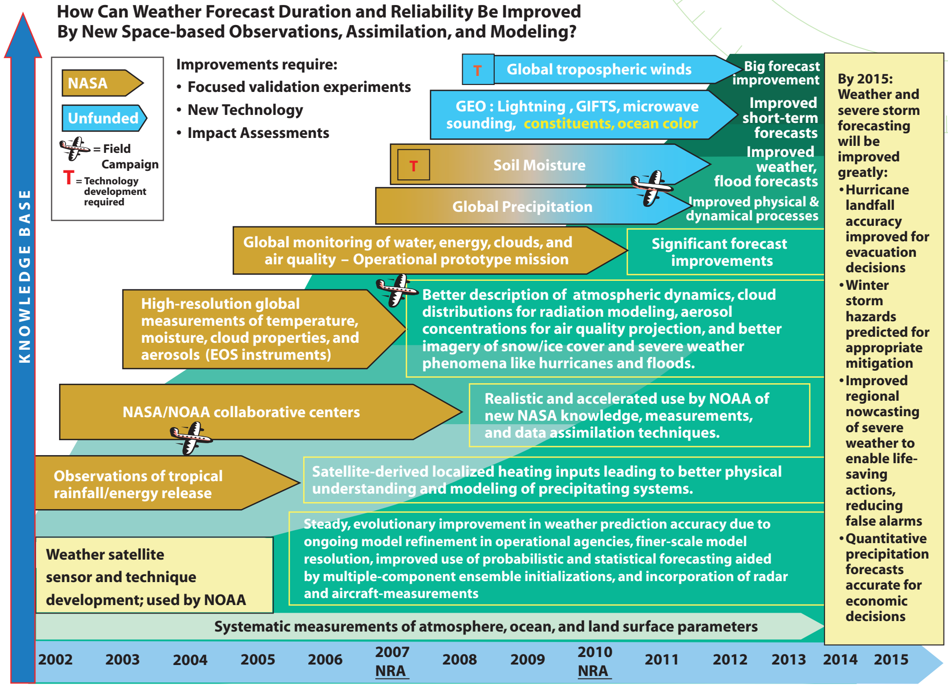
Technology Table
Carbon Cycle & Ecosystems

SCIENCE MEASUREMENT	TECHNOLOGY OPTIONS	CHALLENGES
High Resolution Atmospheric CO$_2$	IR Laser Absorption Spectrometer	2 µm, 3-W CW, Rare Earth Solid State Laser
	CO$_2$ DIAL	2 µm, 1-2 Joule Laser
	Profiling DIAL	1.6 µm Tunable Fiber Laser
	Lagrange Solar Occultation	8 m Fizeau Interferometer
Profiles of Ocean Particles	Imaging Spectrometer	2D Focal Plane Array Detector
	Organic CO$_2$ LIDAR	100 m Ocean Penetrating LIDAR
Physiology & Functional Groups	UV/VIS DIAL	>95% Transmission, 1 nm Bandpass Rejection Filters
New Ocean Carbon/ Coastal Events Observation	VIS/UV Hyperspectral Radiometer	140-band, 5 nm Spectrometer
	UV/IR Event Imager	>20-band, 10 m Resolution Imager
	UV/VIS Spectroradiometer	UV-Capable Spectroradiometer
Vegetation 3-D Structure, Biomass, & Disturbance	RADAR P-Band SAR	100-W, 60% Efficiency Transmitter
	RADAR L-Band SAR	10-kW Transmitter/Receiver
	UV/VIS/IR Hyperspectral Imager	1-2 µm, 2048 x 2048 Detector
	Imaging LIDAR	532 nm Laser Altimeter

RoadMap

Weather

How Can Weather Forecast Duration and Reliability Be Improved By New Space-based Observations, Assimilation, and Modeling?



Improvements require:

- Focused validation experiments
- New Technology
- Impact Assessments

Better description of atmospheric dynamics, cloud distributions for radiation modeling, aerosol concentrations for air quality projection, and better imagery of snow/ice cover and severe weather phenomena like hurricanes and floods.

Realistic and accelerated use by NOAA of new NASA knowledge, measurements, and data assimilation techniques.

Satellite-derived localized heating inputs leading to better physical understanding and modeling of precipitating systems.

Steady, evolutionary improvement in weather prediction accuracy due to ongoing model refinement in operational agencies, finer-scale model resolution, improved use of probabilistic and statistical forecasting aided by multiple-component ensemble initializations, and incorporation of radar and aircraft-measurements

Weather satellite sensor and technique development; used by NOAA

By 2015: Weather and severe storm forecasting will be improved greatly:

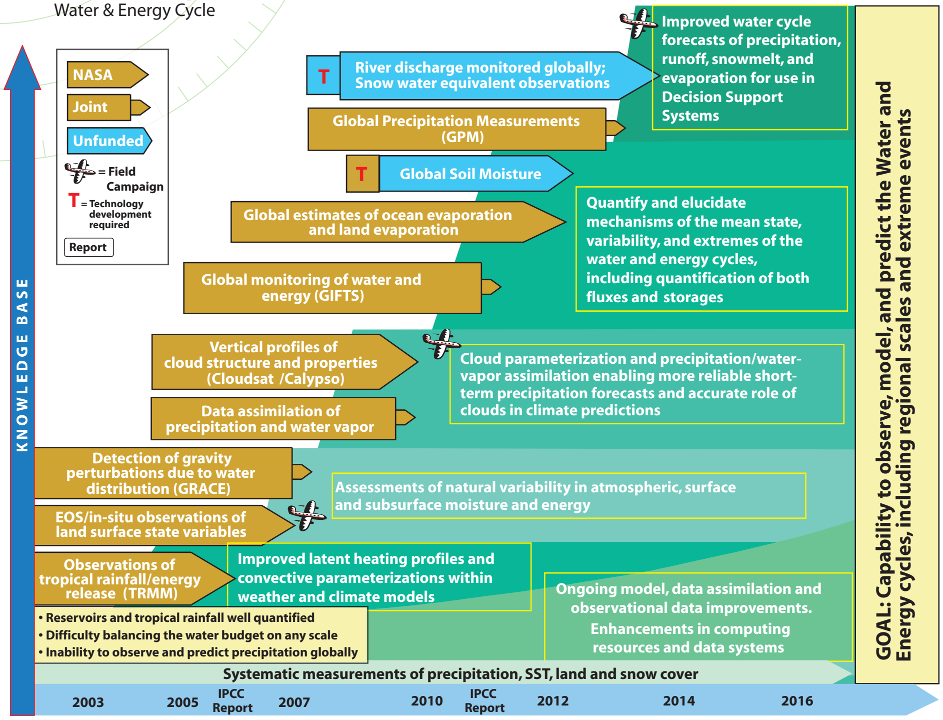
- Hurricane landfall accuracy improved for evacuation decisions
- Winter storm hazards predicted for appropriate mitigation
- Improved regional nowcasting of severe weather to enable life-saving actions, reducing false alarms
- Quantitative precipitation forecasts accurate for economic decisions

Technology Table

Weather

SCIENCE MEASUREMENT	TECHNOLOGY OPTIONS	CHALLENGES
Tropospheric Winds	Hybrid Doppler Wind Lidar	1J @355 nm laser
	Coherent Doppler Wind Lidar	25 mW tunable local oscillator
	Direct Detection Doppler Wind Lidar	10 meter collector
Soil Moisture	UHF/VHF SAR	Large (50 meter) deployable antenna
	L-band Real Aperture Radiometer	25 meter deployable antenna
	L-band Synthetic Thinned Aperture Radiometer (STAR)	Low loss, lightweight L-band feed arrays

RoadMap
Water & Energy Cycle



Technology Table
Water & Energy Cycle

SCIENCE MEASUREMENT	TECHNOLOGY OPTIONS	CHALLENGES
River Discharge Rate • River Stage Height	Interferometer SAR	5m Ka-band (35 GHz) deployable phase array or 5m reflector linear scanning feed
	Lidar	2J@ 2mm 12Hz 1m collector
Soil Moisture	UHF/VHF SAR	Large (50 meter) deployable antenna
	Real Aperture L-band Radiometer	25m deployable antenna
	L-band STAR	Low loss, lightweight L-band feed arrays
Snow Cover, Accumulation, & Water Equivalent	Scatterometer	>3 m diameter deployable mesh antenna with >80% efficiency at Ku-band
	Ku-band Interferometer SAR	10-50m interferometric mast deployable with <0.5 deg phase stability
	Ku/L-band InSAR	10m L-band & 5m Ku-band deployable beam scanning antennas with <0.5deg phase stability
	C/Ku-band Polarimetric SAR	6-20m C-band & 5m Ku-band electronic scanning antennas with 5-8kg/sq-m mass density
	K-band (18.7 GHz) , Ka-band (37 GHz) Radiometer	>6m aperture conical scanning reflector
	1D & 2D Synthetic Thinned Aperture Radiometer (STAR)	K & Ka-band (18.7 & 37 GHz) synthetic thinned aperture radiometer with >150 microwave receiver elements

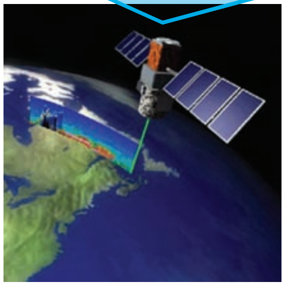
3.0 Technology Thrust Areas

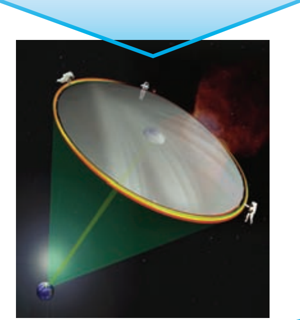
Close linkage between observation, data analysis, and predictive Earth-system modeling activities is a hallmark of the ES research strategy. Analysis of data obtained from observations provides insights that increase our understanding of Earth-system processes. Additionally, observations provide data sets that support the development of new technology and algorithms for future sensors and measurement systems.

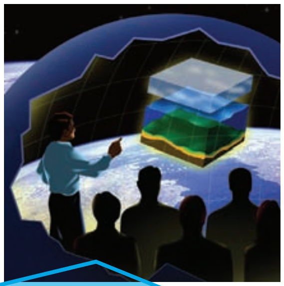
Observing Systems Thrust Area Challenges

Active remote sensing technologies to enable atmospheric, cryospheric and Earth surface measurements

Large deployables to enable future weather/climate/natural hazard measurements







Distributed space-system components for dynamic processing, networking, navigation control, and high-density storage to enable autonomous observing architectures

Interoperable computer frameworks, data fusion, and 3-D visualization techniques to enable information sharing and knowledge discovery for research models

Information and Computing Thrust Area Challenges

Synergy between Earth observation, analysis, and modeling efforts is essential to research activities answering fundamental Earth-science questions, and is a specific contribution of NASA to the U.S. Climate Change Initiative, and the Global Change Research Program. Future improvements in these activities will be enabled by technologies that increase geospatial coverage, accelerate the speed of information exchange, and support the increasingly complex computing environments needed to model Earth-system processes on a global scale.

Evolving Division initiatives characterized by observation, analysis, and modeling activities result in technology objectives that are organized under the **Observing Technologies** and **Information and Computing Technologies** Thrust Areas. Although the program is partitioned into these two areas, the Division's research initiatives remain inextricably interlinked and their technology objectives are interdependent within the overall science-focus framework. A thrust-area orientation is useful because it allows technology managers to tailor their programs in response to unique needs, development aspects, and changing priorities of their product areas. Our two thrust areas encompass the three principal areas of technology emphasis spelled out by the Division's strategy, that is, the Observing Technologies area covers remote-sensing systems, whereas Information and Computing area covers communications and computing systems.

3.1 Thrust Area Challenges

Thrust area needs with the highest priority are identified as **Challenges** the Program must emphasize. Such needs are deemed crucial to implementation of key elements of the Division's science roadmaps and thus receive special attention during the planning and selection process.

3.1.1 Observing Technologies

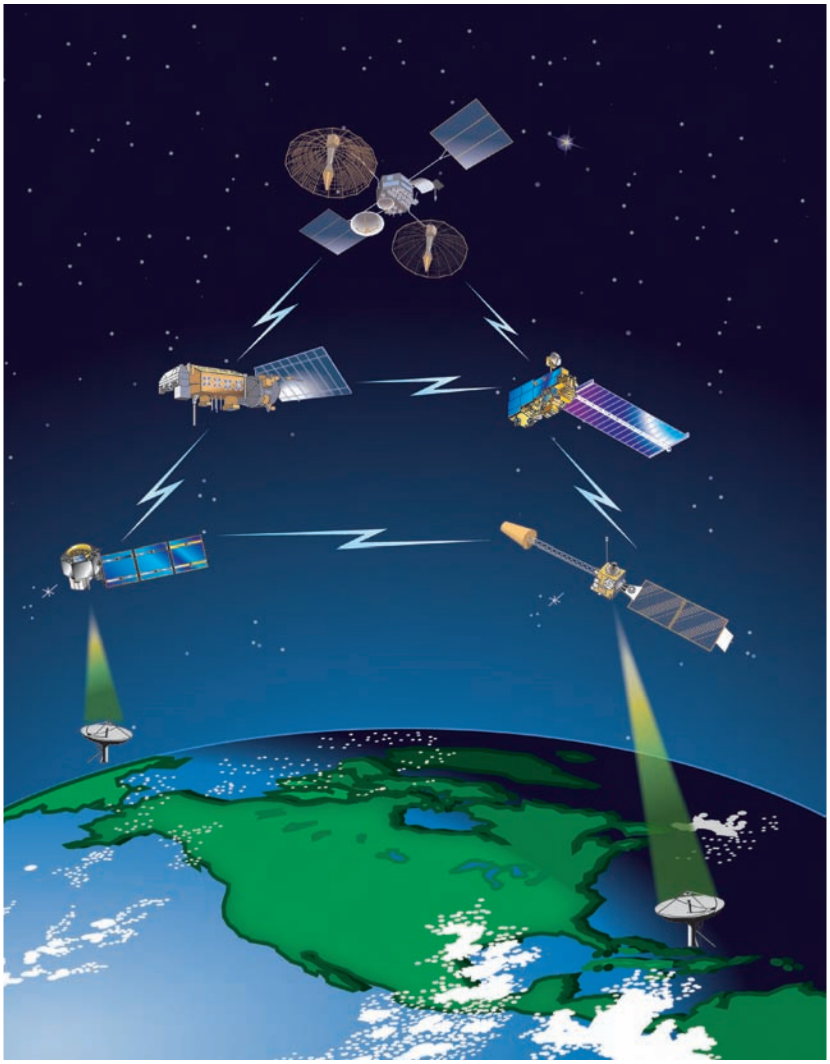
In this thrust area, the Program focuses on sensor and platform advancements that will enable time-crucial or time-continuous observations of the Earth on a global scale. To accomplish this long-term goal, we envision an end-to-end observing architecture that acquires, processes, integrates, and disseminates ES data obtained from vantage points located in space, suborbital locations, and the Earth's surface.

Observing Technology Needs

Technology Area	Primary Needs
Passive optical imaging systems for measurement of land surface, vegetation, ocean, and atmosphere	Improved optical and spectral separation systems to allow reductions in mass and cost; detectors with high pixels counts; on-board processing to reduce data transmission requirements
Passive microwave systems for measurements of atmospheric characteristics, precipitation, soil moisture, and ice and snow	Large, lightweight antenna with multiple-frequency capability; low cost and mass microwave integrated circuits; low-noise, high-frequency receivers
Active optical systems for measuring atmospheric composition	Lightweight, high power, conductively cooled, high efficiency reliable laser systems
Active microwave systems for measurements of precipitation, clouds, land surface topography, and ice and snow	Large, lightweight, deployable antenna systems; radio frequency capability and digital subsystems with reduced mass and cost; on-board processing to reduce data transmission requirements
Formation flying to form large, multi-spacecraft antennas	Precision ranging, precision station-keeping, and autonomous operation

Sensor investments in this thrust area cover the entire electromagnetic spectrum and include both passive- and active-sensing techniques. The strategic emphasis for instrument development is to promote advances that improve spatial, spectral, and temporal resolution of measurements. Optical- and RF-based approaches are the key to remote-sensing advancements and they call for the use of active remote-sensing systems—such as LIDARS and RADARS—that require large telescopes or antennas.

Other instrumentation and platform advancements are intended to increase coverage by enabling observations from geosynchronous orbits and the Lagrange vantage points—two locations found at 1.5 million kilometers away from the Sunlit and dark sides of the Earth—to make possible continuous or global coverage of the Earth's surface for key measurements. Additionally, new technologies will provide advanced platform capabilities needed to build architectures that process data and share information in real time, thus leading the way towards a future where fully integrated sensor systems collaborate unattended to perform complex observations.



In the future, autonomous observing systems that process data and share information in real time will collaborate unattended to perform coordinated observations. New sensor and platform technologies are needed to make these advanced architectures possible.

3.1.2 Information and Computing Technologies

Future observing-architecture concepts envision the use of large numbers of frequency-agile sensors operating from diverse vantage points to provide multi-scene observations. Advanced ‘sensor webs’ will consist of interlinked platforms with onboard information processing systems capable of orchestrating real-time collaborative operations. These architectures will perform data processing needed to detect special events and observing conditions, and to implement the system-wide coordination needed to enable autonomous operations in space. For these observing systems, information technology investments are driven by the need to observe autonomously in a changing environment, and the need to rapidly convert vast amounts of sensor data into operational knowledge and information.

Information and Computing Technology Needs

Technology Area	Primary Needs
On-board Data Processing	Adapt commercial technology to achieve fault-tolerant, high-performance space processors, networks, and storage
Space Communications	Enable adaptable communications by developing high-speed networks and protocols for dynamic space links
Mission Automation	Develop real-time event detection and image recognition, self-tending spacecraft and instruments, and high-level command language for sensor re-targeting
High-performance Computing	Improve Earth-process models by developing next-generation computer modeling techniques, optimizing performance, and developing architectural frameworks to promote model integration
Information Synthesis (Data Discovery, Visualization, and Access to Knowledge)	Derive information from extremely large complex multi-mission data sets; provide tools to assist scientific analysis including real-time science processing and distribution

Investments in this area address the end-to-end information system chain including data acquisition, on-board processing, transmission to ground, storage, data assimilation and modeling, data mining, and distribution of products. In support of this area, advances are required in information architectures, on-board high-speed data processing, and knowledge-management tools.

The ongoing information-technology revolution has been propelled and funded mainly by private industry initiatives and this trend is expected to persist. We will continue to make use of this development base by focusing our investments on commercially developed state-of-the-art technologies that can be converted for space-systems use, and on ground–based systems uniquely suited for management; utilization; or distribution of Earth-system data and information products.

4.0 Program Implementation

4.1 Portfolio Development Process

Program planning identifies capability needs and provides the means to develop and infuse new technologies that satisfy them. Additionally, the planning process serves as the primary linkage between the Program and its customers because it allows technology stakeholders to guide the Program's direction.

Development of the planning process is supported by independent evaluation activities that help maintain the Program's focus on stakeholder needs, and ensure that the Program remains responsive to national priorities. The Division has adopted an integrated planning process that evaluates science-roadmap priorities and systematically carries the resulting requirements through to specific technical performance parameters. This approach maintains traceability of technology developments to Division needs. The planning process also considers near- and mid-term Division implementation plans, as well as far-term projections, to ensure timely technology maturation.

Integrated planning is one of the keys to ensuring effective use of technology-development resources. Towards this end, the Earth Science Enterprise established the Earth Science Technology Office (ESTO) in March of 1998 and assigned it overall responsibility for integrating the Program. In this capacity, ESTO manages the Program and supports the Earth-science Chief Technologist in establishing strategic direction, developing requirements, formulating program elements, and assessing overall program performance.

The planning process begins with the top-level Division planning that identifies science goals, priorities, and implementation time lines. With this guidance as the starting point, program-planning proceeds through four phases that result in a set of periodically updated decision-making products:

1. **Definition** – the Earth-science community defines and validates measurement needs based on focus-area goals. The Program takes these needs and performs system-level assessments to derive corresponding technical-capability requirements. Results of this phase are captured in a database maintained by the Program. The Earth Science Technology Integrated Planning System (ESTIPS) is a comprehensive online database of science goals and technology requirements that serves as a knowledge management tool for strategic planning. ESTIPS users may view Division science needs and measurement scenarios, and can search for specific technology requirements.

2. **Analysis** – the Program conducts system study assessments to (a) translate observing-scenario options into detailed technology performance requirements, (b) compare the relative merits of alternative technology approaches, and (c) identify technical-capability gaps and crucial-need areas. Results of this phase are captured and used by Program planners to define the scope of technology solicitations and guide the selection process.

3. **Development** – the Program prioritizes technology goals and commits resources for their achievement through in-house and

external technology development programs. Specific technology solutions are competitively selected and funded via NASA Research Announcements. An Integrated technology development/investment plan is published yearly by ESTO to document the outcome of the definition, analysis, and development process.

4. **Infusion** – the Program engages stakeholders in planning for the eventual incorporation of new technology products. Although infusion occurs when a technology is formally adopted for a mission, this outcome is fostered throughout the technology-pipeline in several ways. For instance, scientists; technologists; and mission planners are involved in the requirements definition process via community forums. Division science-focus managers participate in the preparation of ESTO solicitations, and during proposal-review activities, to ensure relevance of proposals. Additionally, ESTO reaches out to prospective technology users through an annual technology conference that showcases ongoing developments as well as promising technologies and new concepts. Finally, the entire technology portfolio is documented and made available to the public via NASA's Technology Inventory Database (NTIDB).

The Program periodically updates the databases and documents outlined above and makes them publicly available via NASA web sites and in print through various NASA outreach and education venues.

4.2 Meeting the Program Goals

Fostering the creation and infusion of new technologies into Division missions translates to the pursuit of three strategic objectives: to (1) formulate the best technology portfolio possible, (2) solicit, fund, and oversee tasks that successfully develop technology products, and (3) proactively infuse technologies into Earth-science missions and infrastructure. The end-to-end scope of the Program requires coordinated execution of planning, development, and infusion activities to achieve the overall goal.

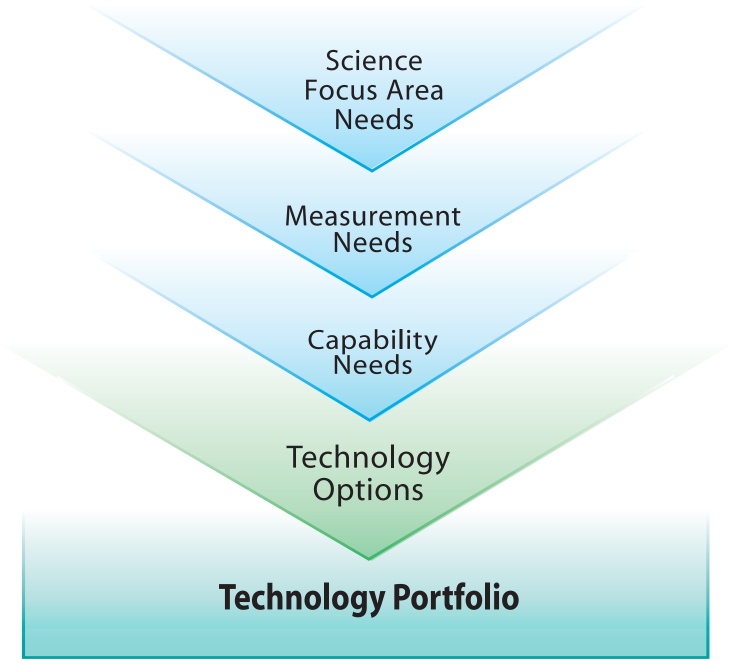


Figure 1: Our planning process uses a waterfall model to provides a well-defined traceability path for every technology product in the portfolio.

To fulfill these strategic objectives, the Division conducts a consolidated Program that establishes a direct linkage between research goals and technology needs, and uses this information to manage a technology portfolio.

Consolidation makes possible the all-encompassing perspective needed to properly balance the capability needs of diverse Division initiatives and to broadly apply technology developments across Earth-science activities. This approach seeks to maximize return on investment—from a Division perspective—by expanding the available technology-solution space, maximizing the use of resources, and enabling technology infusion into a wide range of orbital and suborbital platforms and their support systems.

By applying a “waterfall” model of traceability, the program ensures that technology-development and in-space validation priorities respond to Division goals, and the technology-investment portfolio is optimized to serve overall Earth-science needs (fig. 1).

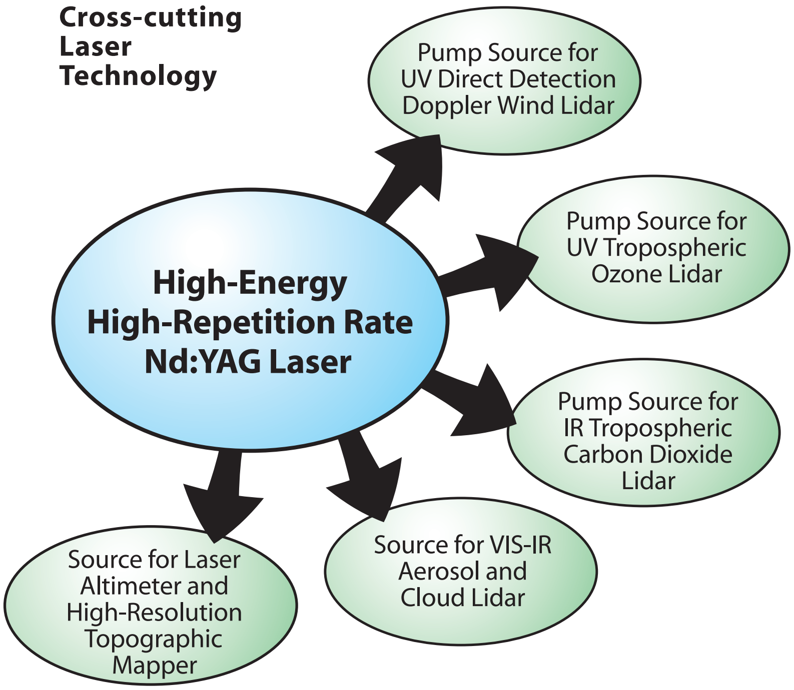
A consolidated Program serves as the focal point for the Division to capture and articulate its technology capability needs to a broad community of science and technology stakeholders, and for activities that lead to partnering and collaboration with other technology programs inside and outside of NASA.

4.3 Portfolio Planning

Planning activities help align the technology-investment portfolio with Division needs. Portfolio planning involves dealing with technical disciplines that include sensors, instruments; information systems; computing devices; and platforms, and technologies that range from the component level to complete systems and Division-level architectures. Science needs within these disciplines are identified and validated by the Earth-science community and documented by the Program. Needs are then analyzed through feasibility studies, technical trade studies, and system and architecture studies to derive technical-capability needs and technology implementation options. Study and assessments activities are supplemented by workshops that develop technology projections and road maps that further refine the technology trade space.

Portfolio planning activities culminate in technology solicitations, whereby the Division selects proposals submitted by technology developers for funding. Solicitations are a crucial step in the Program's implementation because they are the primary means for inclusion of technologies in the portfolio.

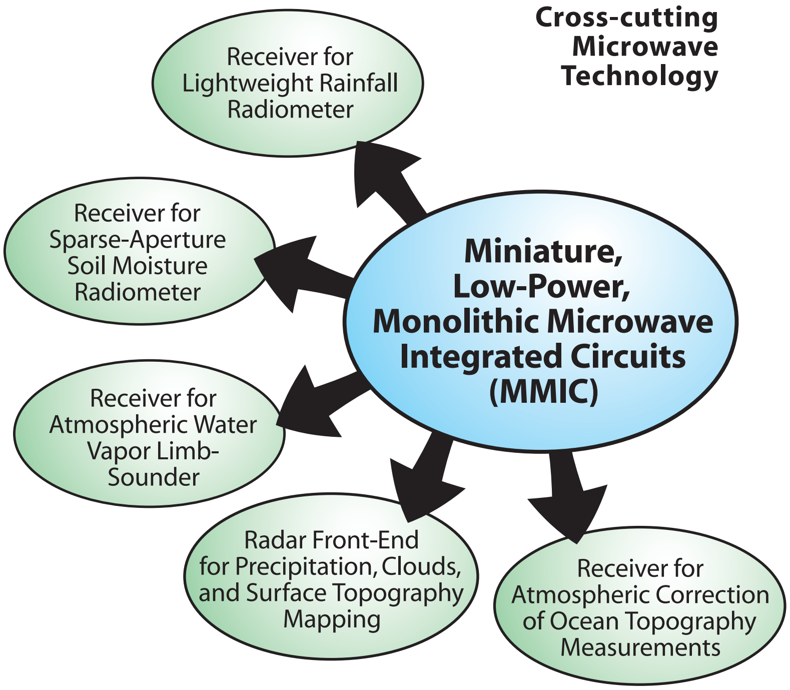
Requests for proposals are formulated through a process that begins with a gap analysis that identifies candidate technology areas for the call, continues through identification of a specific technology focus for each area of the solicitation, and ends with Division approval and formal release of the solicitation to the public.



Program planning maintains a solicitation schedule with the intent of conducting at least one solicitation per year—with a biannual rate for each of the technology areas—as funding allows.

An important outcome of the planning process is the identification of technologies with potential for application across focus areas, or to several measurements within a focus area, because it highlights opportunities to improve return-on-investment by increasing the infusion rate.

In addition to guiding portfolio formulation efforts, the planning process involves assessment and development of observing-system architectural concepts for future missions. These activities support efforts to advance the state-of-the-art of instrumentation for the focus areas, and are intended to provide a forward-looking perspective that seeks to continuously advance the capabilities of the Division's observation and information management infrastructure. One area of interest for the planning process is studies leading to the definition of observing-system concepts for the Earth's neighborhood region of space, and for concepts for future deployment and integration of international systems that will provide global coverage or coordinated data suites. These assessments sometimes complement the work of other NASA Divisions or entities such as the Global Earth Observation System of Systems (GEOSS) international group.


Cross-cutting Microwave Technology

4.3.1 Infusion of Technologies

The Division has adopted an end-to-end approach to encourage technology infusion through planning, distributed task management, and outreach. Program activities promote infusion planning in several ways:

- For the long-term, technologists support Division focus-area strategic planning and road-mapping activities to identify future technology needs and infusion opportunities.
- For the mid-term, technologists support science-working groups to assist in the formulation of measurement concepts and system design approaches that incorporate anticipated technology developments.
- In the short-term, technologists support studies that identify potential risks and payoffs of including specific technologies in projects during formulation.

Infusion is promoted during the technology development cycle by assigning task-management responsibilities to NASA Centers with relevant expertise. By assigning management responsibility to Centers close to potential end users, the Division provides cognizance and familiarization, a sense of ownership, and links to potential infusion for given technologies.

Infusion activities for maturing technologies are focused on educating potential users about the benefits of new technologies. This education takes several forms, including public forums that highlight technology advancements, reporting in journals and periodicals, and by direct involvement with Division outreach initiatives.

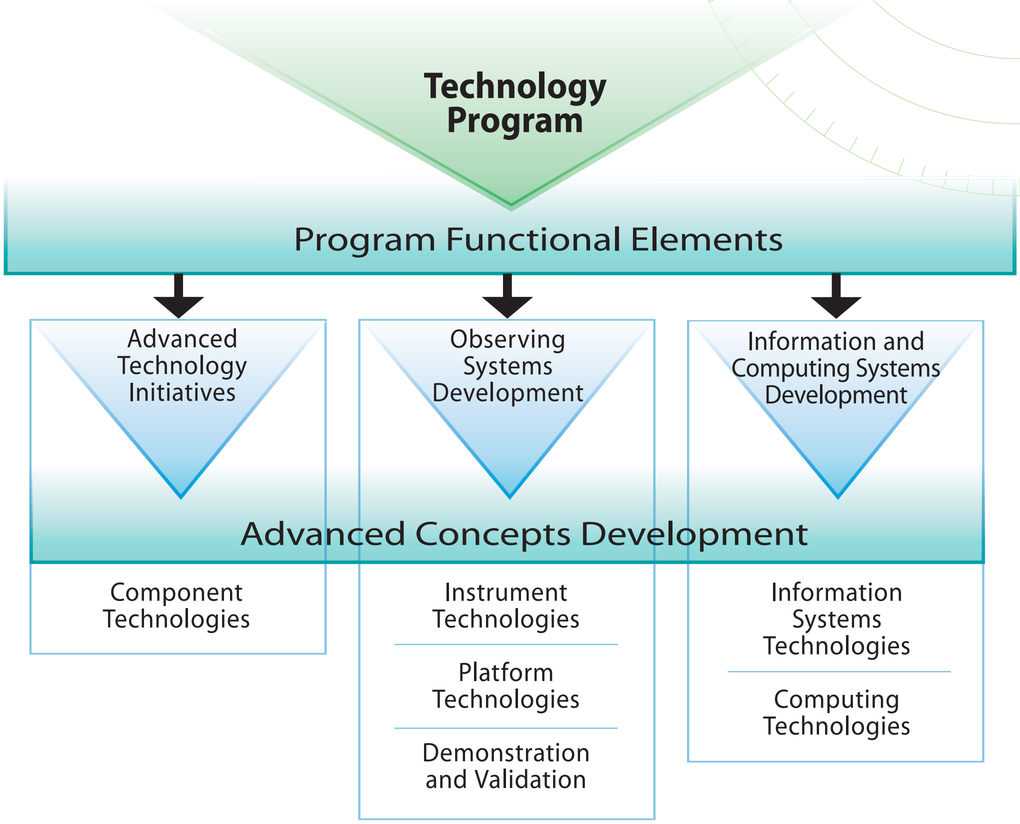


Figure 2: Program activities are carried out by functional elements that address unique planning and development needs of their assigned technology areas.

4.4 Program Elements

Program implementation is assigned to functional work elements tailored to meet various needs of the Program's plan (fig. 2). These elements address different areas of the technology-development pipeline as described ahead. Within these program elements, system studies and technical assessments provide information needed by program managers to support their technology-planning decisions.

A key goal of the technology strategy is to collaborate with external technology programs that deliver products addressing technical-capability needs of the Division and that may yield benefits for specific Division initiatives. This goal dictates the formulation of elements that can benefit not only from their own technology development initiatives, but also from external programs supported by other NASA Directorates, government agencies, and the private sector. Fostering of strong partnerships with external entities is therefore an important ongoing activity within the Program's work elements.

4.4.1 Advanced Technology Initiatives

Advanced Concept Development (ACD)

ACD conducts advanced-concept initiatives and studies to stimulate the generation of new science, application, and technology concepts. This program element is unique in that its activities support all the other technology-program elements and top-level Division study efforts.

Studies are used to explore new ideas for component, system, and architectural concepts with a far-term horizon of 10 to ~25 years that are based on futuristic science scenarios. Additionally, ACD supports the development of advanced concepts for near- and mid-term needs by conducting focused studies that prioritize needs, define technology roadmaps, and refine candidate-observing scenarios.

Advanced Component Technologies (ACT)

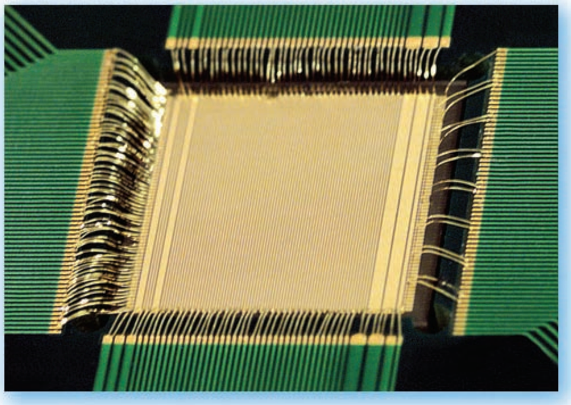
ACT focuses on advancing the state-of-the-art of components and subsystems that serve as basic building blocks for instruments, platforms, and information systems. Once advanced concepts are identified, ACT selects key long-lead component-level technologies and supports their development. Additionally, this element seeks other technology programs—within national and international agencies, and U.S. private industry—that pursue component development to collaborate with them to meet common technology needs.

Detector developments enable new imaging techniques that will improve scientific remote sensing, industrial monitoring applications, and medical diagnosis instrumentation.

4.4.2 Observing Systems Development

Instrument Incubator Program (IIP)

IIP supports development of instrument system and subsystem technologies to bring them to a level of maturity where they are ready to be proposed to NASA Announcements of Opportunity. As part of their maturation activities, key IIP technologies sometimes undergo sub-orbital validation—in laboratories, balloons, or airplanes—to demonstrate operational capabilities in a low-cost, low-risk environment. IIP awards are typically allocated to innovative, high-payoff instrument and measurement-system technologies selected via a competitive process.



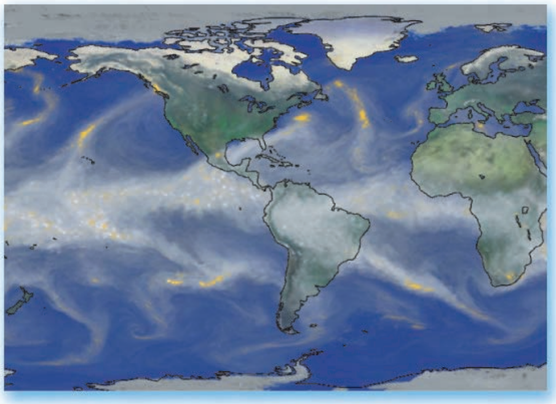
Integrated-circuit developments enable reconfigurable, low-power, radiation-hardened electronic components that will improve the capabilities of our space instruments and platforms.

Advanced Platform Technologies (APT)

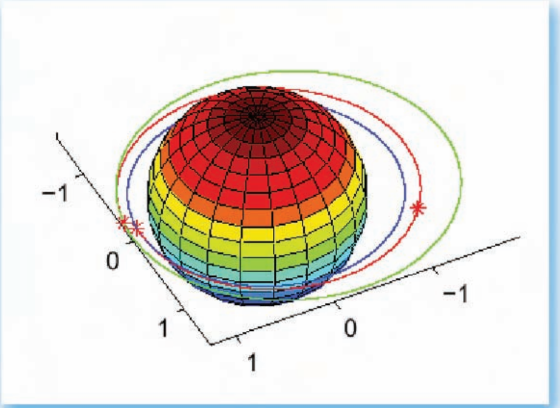
Platforms serve as host systems for sensor payloads by providing on-orbit services such as power, pointing, environmental control, management of payload 'health and safety', science data processing, and data links to the ground. APT pursues developments to reduce size, power, volume, and other sub-system resource requirements for space-, airborne-, and surface-based platforms.

Technology Validation

The Division's approach for technology validation is to exercise high-risk technologies in science or demonstration flights of opportunity. Flight opportunities occur on various NASA missions, as well as on missions sponsored by external partners such as the Department of Defense. In some cases, the Division may elect to sponsor unique missions designed to validate crucial technologies identified in its science roadmaps.



Developments in software computing frameworks enable coupled Earth-system models that will improve future weather and climate forecasts.



Mission planning and scheduling software developments enable unattended mission operations that will improve space-based global observations.

4.4.3 Information/Computing Systems Development

Advanced Information System Technologies (AIST)

AIST developments advance end-to-end data system capabilities for collecting, transmitting, processing, disseminating, and archiving information about the Earth system. The primary goal for these developments is to enable the effective generation and use of Division data products in both the public and private sectors.

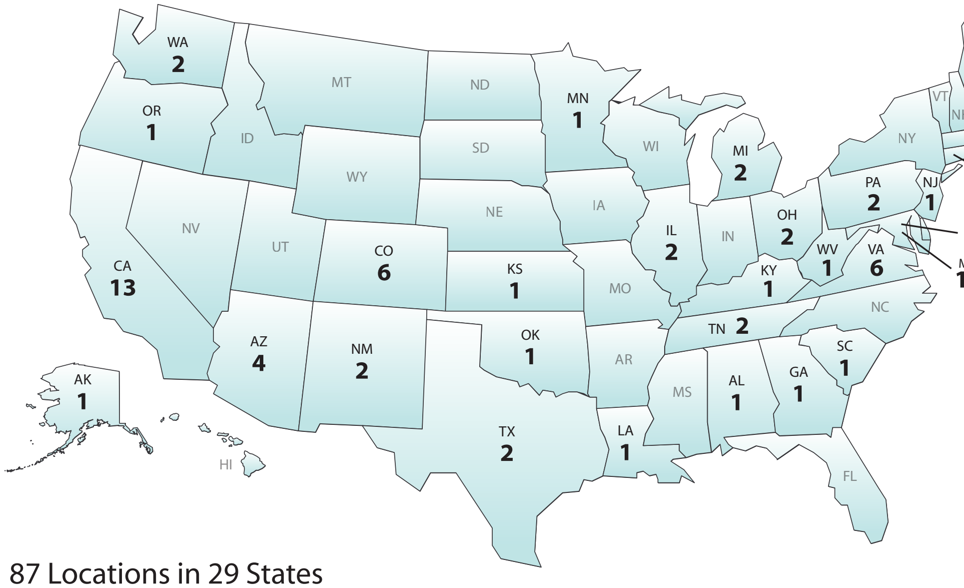
Computing Technologies (CT)

Computing technologies include advanced, high-risk/high-payoff computational science methods and system implementation techniques that benefit the Division, and that help sustain the U.S. competitive position in the computing arena. It focuses on development of specialized modeling frameworks that will support dynamic and interactive modeling of Earth's processes. These developments will provide the foundation for a fully integrated Earth-system model. CT pursues technologies expected to be ready for infusion out to a ~20-year horizon.

4.5 Program Partners

Partnering opportunities occur at all levels of the technology-development pipeline. These opportunities are filled though openly competed solicitations to ensure that the best new ideas are brought to bear on our technology challenges. Our partner base is widely distributed over the United States as illustrated by the map below, which shows external collaborators since the inception of the Program.

Regional Distribution of Partners



87 Locations in 29 States

4.5.1 Internal (NASA) Partners

NASA Centers are the engines of progress in Earth System science. Scientists at these Centers conduct leading-edge research that complements the work done at the nation's universities and that helps assure the quality of our space and sub-orbital observing programs. Centers serve as NASA's principal program and project managers to develop, plan, and implement Earth-science Division missions and thus play a key role in our technology planning and infusion processes. Also, Centers possess unique discipline skills in engineering and technology development that are the core of our in-house technical competency.

Other NASA Directorates conduct technology programs and the Division works closely with them to avoid duplication of effort and to identify common needs that may lead to collaboration. Linkage between these technology programs occurs through technology workshops, relevancy reviews, and solicitations. In many cases, joint funding is applied towards development of crosscutting technologies.

Supporting NASA Centers

Ames Research Center
Glenn Research Center
Goddard Space Flight Center
Langley Research Center
Marshal Space Flight Center

4.5.2 External Partners

External partnerships with government, academia, and private industry are a vital extension of our technology development program. Technology developers around the nation are directly involved in conducting fundamental research, inventing new technologies, designing new systems, and helping to apply their knowledge and results to advance our technical capabilities. Many of these partners conduct basic research that eventually leads to technology innovations, and these contributions directly sustain our technological edge.

Academia

- American University
- California Institute of Technology
- Carnegie Mellon University
- Clemson University
- Colorado State University
- Drexel University
- George Mason University
- George Washington University
- Georgia Institute of Technology
- Harvard University
- Howard University
- Johns Hopkins University
- JHU/Applied Physics Lab
- Michigan Tech
- MIT
- Morehead State University
- Ohio State University
- Ohio University
- Oregon State University
- Rutgers University
- Stanford University
- Tulane University
- UCLA
- University of Alabama, Huntsville
- University of Alaska
- University of Arizona
- University of California, Berkeley
- University of California, Santa Barbara
- University of Chicago
- University of Colorado, Boulder
- University of Illinois, Urbana-Champaign
- University of Kansas
- University of Maryland
- University of Michigan, Ann Arbor
- University of Oklahoma
- University of Rhode Island
- University of Tennessee
- University of Texas, Austin
- University of Virginia
- University of Washington
- USC/Information Sciences Institute

Federal Laboratories

- Aerospace Corporation
- Air Force Research Lab
- Jet Propulsion Laboratory
- Lawrence Berkeley NL
- Naval Research Lab
- NCAR
- NOAA NWS
- NOAA/CMDL
- Oak Ridge National Laboratory
- Pacific Northwest National Laboratory
- Sandia National Laboratory

Small Corporations

- AER, Inc.
- Aerodyne Research
- ASRC Aerospace Corp.
- Barr Associates, Inc.
- BNN Technologies
- ECOlogic Systems Corporation
- Electro Energy, Inc.
- Fibertek, Inc.
- Global Aerospace Corporation
- GST
- Institute for Software Research, Inc.
- LiteCycles, Inc.
- Paradigm Computing LLC
- PicoDyne, Inc.
- Polatomic, Inc.
- QorTek, Inc.
- Q-Peak, Inc.
- QSS Group, Inc.
- SES, Inc.
- SGT, Inc.
- Simpson Weather Associates, Inc.
- Spectrum Astro
- SSAI
- Syagen Technology, Inc.

Large Corporations

- BAE Systems
- Ball Aerospace & Technologies
- CSC
- Draper Lab
- Hamilton-Sunstrand
- Hughes Information Technology Co.
- ITT Industries
- Lockheed Martin
- Lockheed Palo Alto Research Laboratory
- Raytheon
- SAIC
- TRW Space and Electronics Group

4.6 Program Outcomes

The overarching goal of the Program is to develop and infuse new technologies into Earth-science missions and infusion results are the best indicator of Program performance. This metric is best illustrated by a pie chart showing infusion percentages for completed tasks. Tasks are considered complete when they mature to a readiness level where they may be infused—that is, proposed for missions; research campaigns; or demonstrations—and will not receive additional development funding.

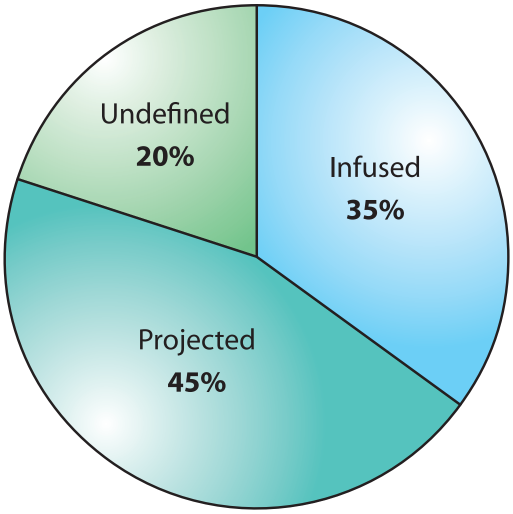
Since the Program's inception, a total of 258 technology tasks have reached completion status, of which 76 have been **infused**. For the remaining tasks, **projected** indicates that the technology has a well-defined end user and **undefined** indicates there is no planned end-use for the technology.

At the end of 2003, a total of 80% of the Program's completed technologies had either found use on science projects, or had concrete infusion plans. It is notable that studies—which produce information for planning purposes that is not intended for infusion—are included in the undefined category. Finally, a fraction of technologies in the undefined category represent program sunk costs because they did not mature as anticipated and will never reach infusion.

In addition to the completed tasks, there were 136 active technology tasks in the 2003 portfolio that were not included in the pie chart. The number of active tasks varies yearly because it decreases as tasks are completed and increases as solicitations bring new tasks into the portfolio.

INFUSION RESULTS

76 Infused	The technology was used in a flight instrument or has flown successfully on aircraft demonstrations or research campaign flights.
123 Projected	The technology has a well-defined future end use or customer.
59 Undefined	The technology does not have a planned end use or customer.



4.6.1 Evaluation and Review Mechanisms

To augment the internal development of the technology planning process the Division has engaged internal and external review bodies that independently evaluate and make recommendations on a semi-annual basis.

The Technology Steering Team is a group of engineering and technology experts from NASA Centers that serve as the internal review body. For the external review, a Technology Subcommittee from of the Earth System Science and Applications Advisory Committee (ESSAAC) performs the review function. ESSAAC is an independent body that advises and makes recommendations to the Earth Science Associate Administrator. The ESSAAC Chairperson is a member of the NASA Advisory Council that advises the NASA Administrator and the NASA Advisory Council on the full scope of Earth-science strategic goals, execution, and performance. ESSAAC meets twice yearly and its plans and proceedings are published in the Division's web site. These groups, along with Division management, the community, and ES stakeholders provide overall guidance and oversight to the Program.

4.6.2 Success Criteria

Performance is measured yearly against criteria established at key planning and implementation levels of the Program. Criteria are reviewed and updated periodically to ensure effectiveness in measuring program results. The assessment process examines the program's content and structure, and evaluates results against the three performance metrics outlined below:

1. Advance 25% of funded technology developments one Technology Readiness Level (TRL).
2. Mature at least two technologies to the point where they can be demonstrated in space or in an operational environment.
3. Enable at least one new science measurement capability, or significantly improve the performance of an existing one.

In addition to measuring program results, the assessment process ensures accountability to Division management and compliance with national directives such as the Government Performance Results Act of 1993, and the President's Management Agenda of 2002.

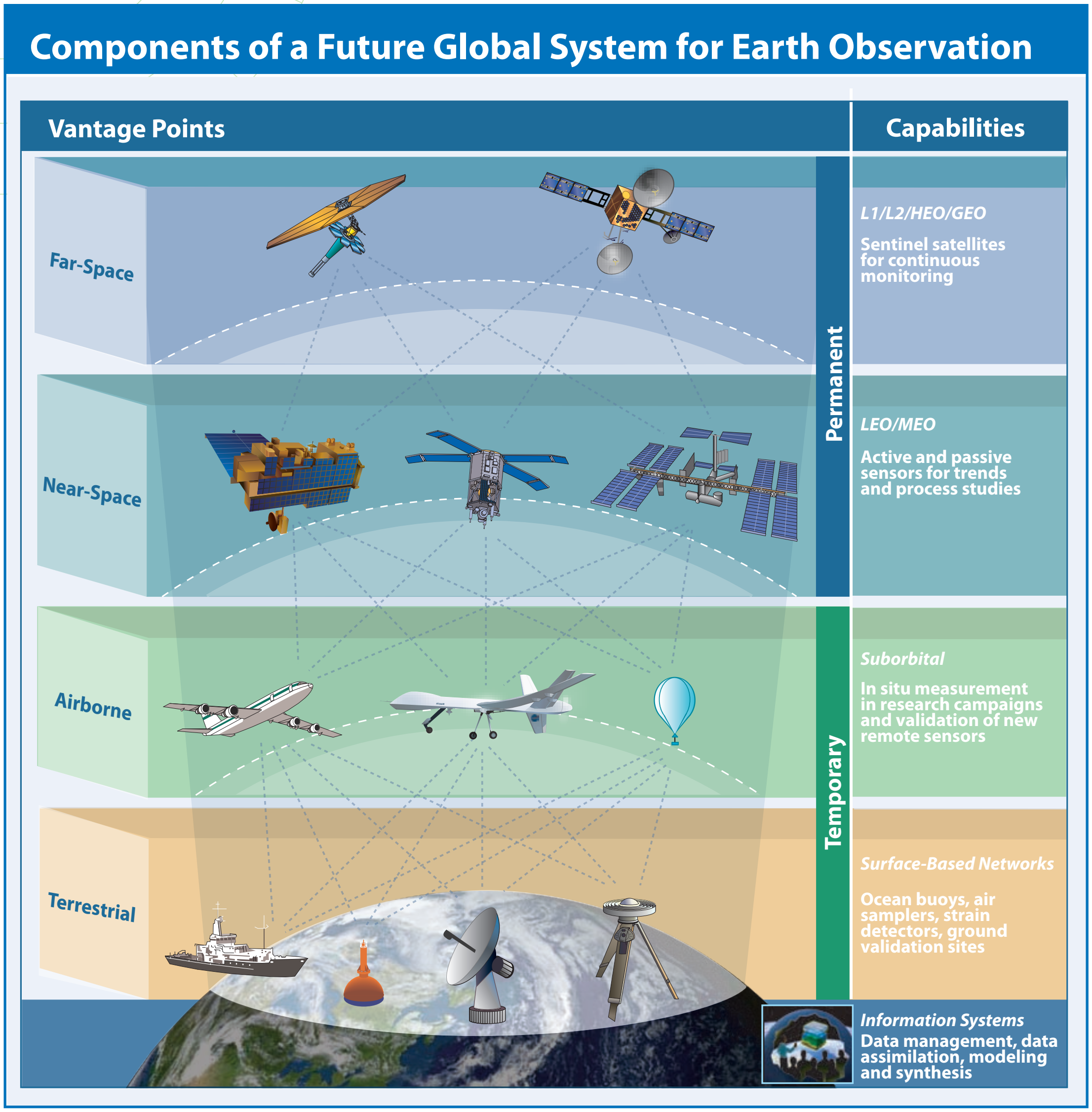


Figure 3: Interconnected platforms at diverse vantage points are an essential component of a future end-to-end Earth science observing system capable of monitoring the Earth on a global scale.

5.0 ES Technology for the 21st Century

The grand challenge of the 21st century for Earth Science is to answer the question “How is the Earth changing and what are the consequences for life on Earth?” The pathway towards the answer is a series of science questions we must answer to understand how various components of the Earth’s system work. Integrating our scientific understanding of the major components of planet Earth to achieve a holistic understanding of how it functions is an essential step toward reliably predicting its future course of change.

The challenge for the scientific community and NASA will be to develop an inclusive Earth-system model suite integrating remote sensing, suborbital and in situ measurements with accurate predictive capabilities. Such a suite would advance our understanding of couplings between different processes that occur at different spatial and temporal scales, thereby enabling scientists to better explain local and regional changes in their global context.

An observing, modeling, and information management system enabling research and applications for the 21st century will employ sensors in various terrestrial and orbital locations as illustrated by Figure 3. Its sensors will be dynamically linked to allow the observing system to communicate in real time with ground-based modeling and information-management systems. This interactive capability will provide the foundation for a future system that autonomously collaborates to plan observing strategies, can execute them unattended, processes the resulting data, and delivers information products directly to end users. Under this scenario, users will be able to receive customized information products directly at their desktops in near-real time on a regular basis.

The task for NASA’s Earth Science programs is to enable this future vision through the delivery of reliable products from a space-based observing system, improvement of predictive models based upon emerging scientific research, and deployment of information systems capable of handling vast amounts of data products. Achievement of this goal will require a sustained focus on Earth system science and the development of technologies that support expanded observational; computational; and data-management capabilities, and that reduce mission cost; risk; and development times as well.

NASA is in a unique position to lead the development of this highly complex end-to-end scientific research system, especially by developing new remote-sensing technologies for space and by engineering new architectures for advanced observing systems needed to conduct complex observation strategies on a global scale.

In this regard, our Thrust Area challenges already define new capabilities needed to begin the work of building precursors for such systems. The technology program is prepared to contribute to the realization of this vision by leading the development of advanced technological capabilities that will include:

- Sensors to improve spatial, spectral, and temporal resolution.

- Communication and computing components to enable real-time communications and data processing in space.

- Platform systems and supporting infrastructure to provide global observing capabilities through the use of geosynchronous, moon-based, and Lagrange vantage points.

- Computing components and algorithms needed to build advanced information architectures that employ knowledge management tools to support research efforts and to disseminate products directly to users.

It is clear that technology development will remain an essential element of the Division's Science for Society Framework, and that the Program's task for the 21st century will be to contribute by leading the efforts to develop ***a new generation of technologies*** needed to achieve our Division's goals.

This contribution will help NASA's Earth Science research and applications programs sustain their leadership role in meeting the scientific challenges of this 21st century and in 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.

6.0 Acknowledgements

The Earth-Sun System Technology Office would like to express appreciation for the work undertaken by the Earth Science community in the development of the ES Technology Plan.

Also, our thanks go to members of the Earth-Sun System Division external review teams, NASA Headquarters staff, our many collaborators at the NASA Centers, and to ESTO members that contributed to the preparation and review of this document.

George J. Komar
ESTO Program Manager

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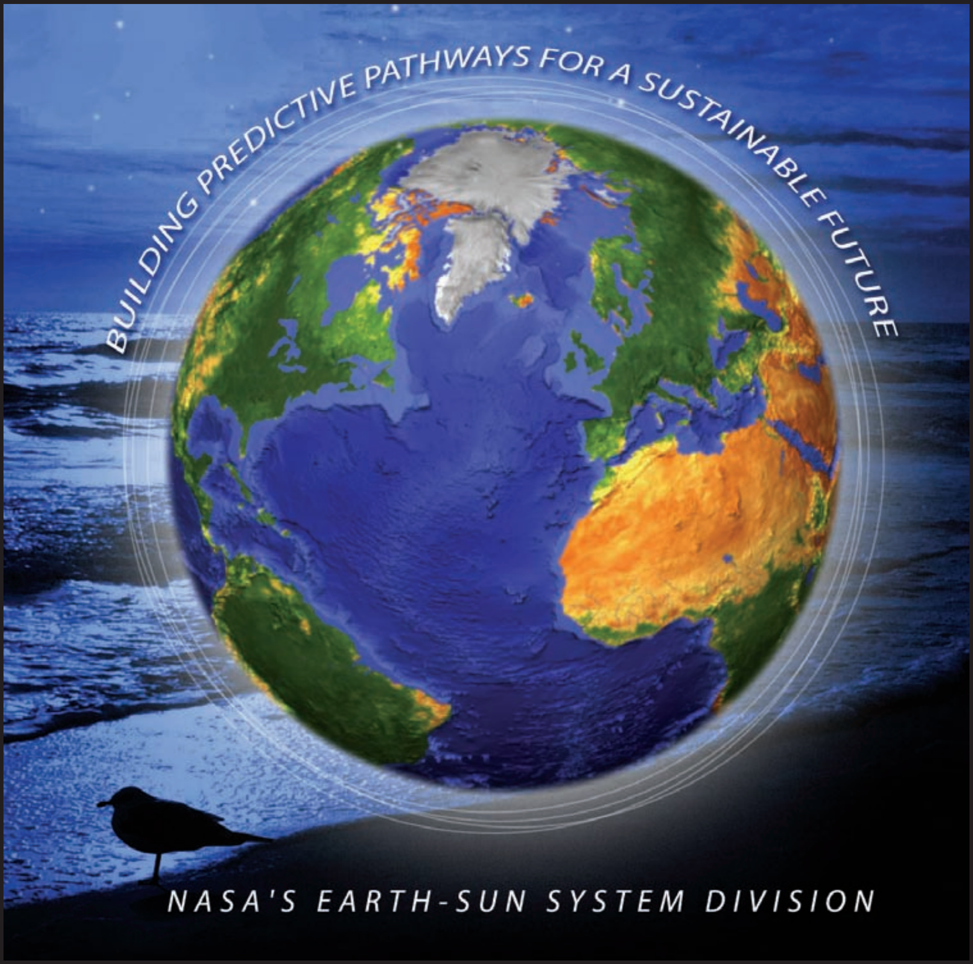
For more information regarding the work of
the Earth-Sun System Technology Office,
please visit our Web site:
http://www.esto.nasa.gov



BUILDING PREDICTIVE PATHWAYS FOR A SUSTAINABLE FUTURE

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