National Aeronautics and Space Administration

2009 annual report

Earth Science Technology Office

On the Cover:
Top row from left to right: UAVSAR pod (see page 8) with cover removed for service - image credit: Dave Bullock, Wired.com; NASA P-3 aircraft with PARIS radar (see page 8) taxiing on a snowy runway in Greenland - image credit: NASA Operation Ice Bridge; optics hardware for the TIMS Instrument (see page 4) - image credit: John Kumer.
Middle row from left to right: An assembled, adaptively-controlled 2.4 meter antenna reflector (see page 13) - image credit: Houfei Fang; a brassboard of a superconductor-insulator-superconductor mixer for microwave limb sounding (see page 12) - image credit, Karen Lee; a topographic image taken by a new Ka-band radar (see page 5) - image credit: Delwyn Moller.
Bottom row from left to right: students with a meteorological station in Alaska - image credit: Matt Heavner; a digital radio frequency interference detector - image credit: Christopher Ruf; a volcano "spider" on Mount St. Helens (see page 11) - image credit: USGS.

Executive Summary

As reported in the pages that follow, 2009 has been another active year for NASA Earth science technology development. The NASA Earth Science Technology Office (ESTO) is entering its 12th year supporting and enabling new science measurements, operational requirements, and practical applications that benefit society at large.

Activities over the past two years have centered on guidance provided by the National Research Council (NRC) of the National Academies in the first Decadal Survey for Earth science: "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond." At the release of this Decadal Survey in 2007, we were pleased to note that existing ESTO investments already applied directly to the 18 recommended mission concepts. Moving forward, ESTO has carefully focused new investments toward these measurement goals. This annual report contains a special section – "Toward the Decadal Survey" on page 8 – that illustrates how these new investments support the Decadal Survey.

In Fiscal Year 2009 (FY09), ESTO awarded funding to 37 new projects – 17 through an Advanced Component Technologies program solicitation and 20 through an Advanced Information Systems Technology Program solicitation – which brings the total ESTO portfolio to more than 600 active and completed technology investments. The next solicitation, for the Instrument Incubator Program, is planned for release in FY10.

ESTO also continues to build upon a strong history of technology development and infusion. In FY09 over 50% of active ESTO technology projects advanced at least one Technology Readiness Level (TRL). Many projects have also achieved actual infusion into science measurements, system demonstrations, or other applications. Of the 505 projects in the ESTO portfolio that are complete, 35% have already been infused and an additional 44% have a path identified for future infusion.

We are proud of the contributions that our principal investigators make for the future of Earth science and we look forward to another year of innovations in FY10.

George J. Komar **Amy Walton**

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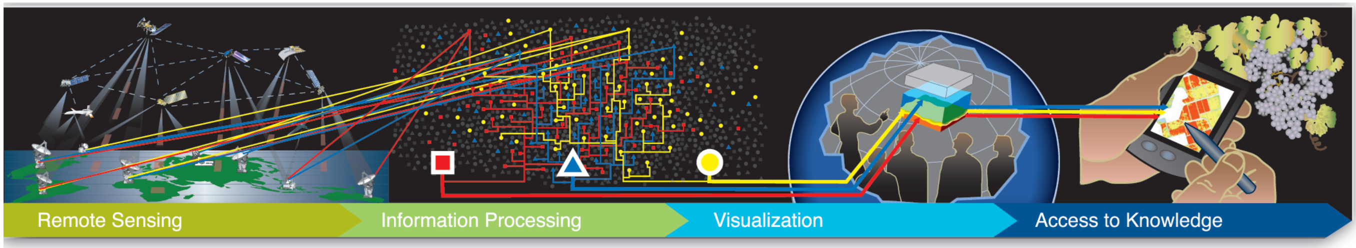


From instruments to data access, ESTO technologies enable a full range of scientific measurements

As the lead technology office within the Earth Science Division of the NASA Science Mission Directorate, the Earth Science Technology Office (ESTO) performs strategic technology planning and manages the development of a range of advanced technologies for future science measurements and operational requirements. ESTO technology investments attempt to address the full science measurement process: from the instruments and platforms needed to make observations to the data systems and information products that make those observations useful.

ESTO's approach to technology development is also end-to-end:

- Planning technology investments through comprehensive analyses of science requirements
- Selecting and funding technologies through competitive solicitations and partnership opportunities
- Actively managing funded technology development projects
- Enabling infusion of technologies into science measurements and missions.

ESTO employs an open, flexible, science-driven strategy that relies on competitive, peer-reviewed solicitations to produce the best cutting-edge technologies. In some cases, investments are leveraged through partnerships to mitigate financial risk and to create a broader audience for technology infusion.

The results speak for themselves: a broad portfolio of over 600 emerging technologies that can enable and/or enhance future science measurements as well as an ever-growing number of infusion successes.

2009 Metrics

With more than 500 completed technology investments and a current, active portfolio of nearly 100 projects, ESTO is driving innovation, enabling future Earth science measurements, and strengthening NASA's reputation for developing and advancing leading-edge technologies.

How did ESTO do this year? Here are a few of our successes for fiscal year 2009 (FY09), tied to NASA's performance goals for ESTO:

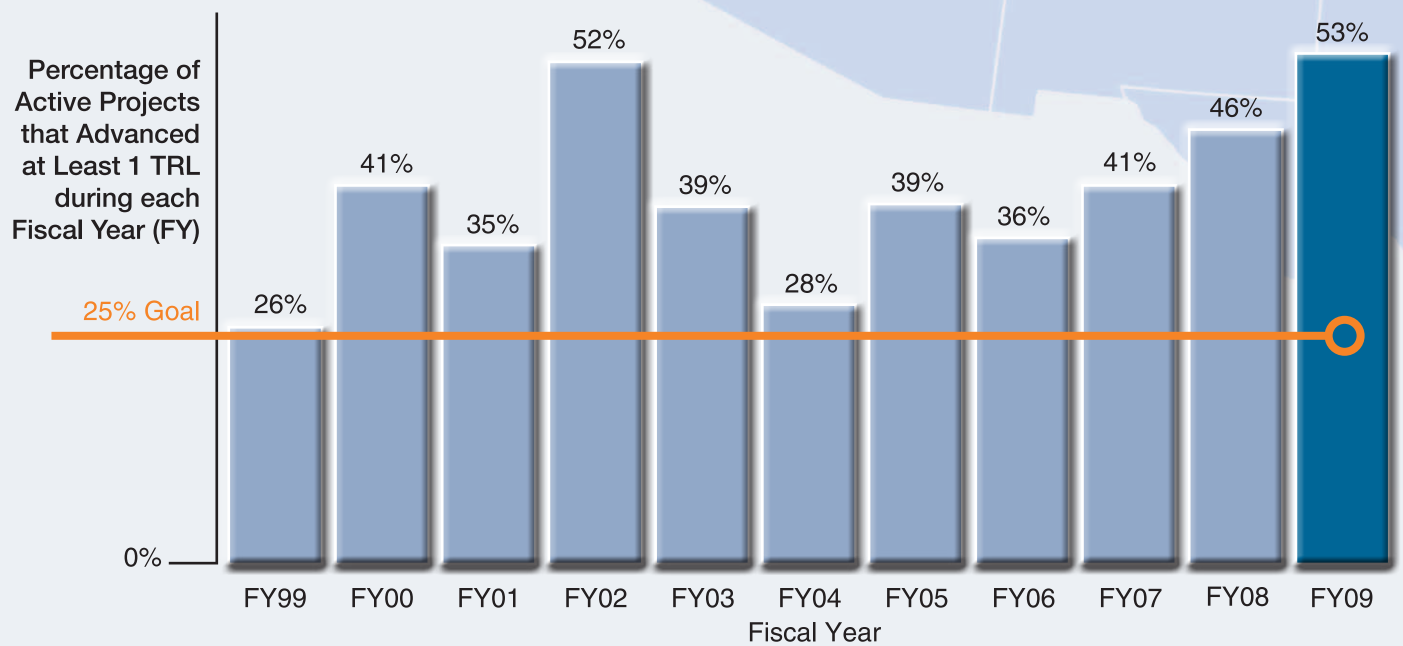
Each dot represents one of the 601 projects (active and completed) in the ESTO portfolio.

GOAL:

Annually advance 25% of currently-funded technology projects at least one Technology Readiness Level (TRL).

FY09 RESULT:

53% of ESTO technology projects which were funded during FY09 advanced at least one TRL over the course of the year. 15% of these projects advanced 2 TRLs and one project advanced 3 TRLs. See the graph below for yearly comparisons of this metric.



GOAL:

Mature two to three technologies to the point where they can be demonstrated in space or in a relevant operational environment.

FY09 RESULTS:

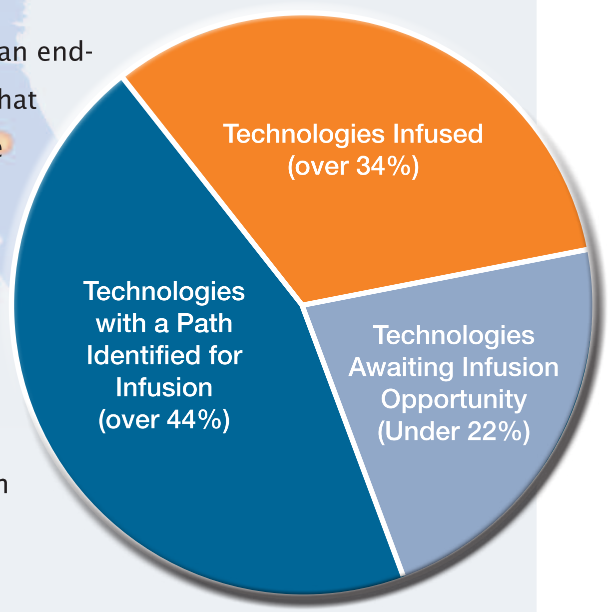
Numerous ESTO projects achieved infusion into space missions or airborne science campaigns in FY09. Several notable examples follow:

- Between March and May 2009, the **Pathfinder Advanced Radar Ice Sounder (PARIS)** participated in data collection flights onboard the NASA P-3 Aircraft over Greenland for the IceSAT Gap Filler campaign. PARIS is a radar instrument designed to sound the basal (bottom) topography and internal layering of ice sheets from high altitude.

- The **Far Infrared Spectroscopy of the Troposphere (FIRST)** instrument is currently deployed and collecting science data in a field campaign in the high Atacama Desert in Chile. As part of a science campaign with the Department of Energy's Atmospheric Radiation Measurement (ARM) program, investigators from the U. S., Germany, and Italy are conducting a 3-month "Radiative Heating in the Underexplored Bands Campaign" from a mountaintop site at 17,500 feet. The goal of the campaign is to conduct experiments in the far-infrared portion of the Earth's infrared emission spectrum.

- The **Sensor Web Operations Explorer (SOX)** task has developed an end-to-end Observing System Simulation Experiment (OSSE) system that enables Earth atmospheric scientists to comprehensively analyze science return from a wide range of mission and instrument concepts. During FY09, this capability was infused into the GEO-CAPE mission study to enable rapid evaluation of observation scenarios, measurement quality ranges, and retrieval analysis performance. The GEO-CAPE study team obtained quantitative science impacts on combining UV/VIS and IR observations, on the trade-offs of spectral resolution, and on integrating low Earth orbit observations.

ESTO's Infusion Success - drawn from the 505 completed projects through FY09



2009 Metrics Continued

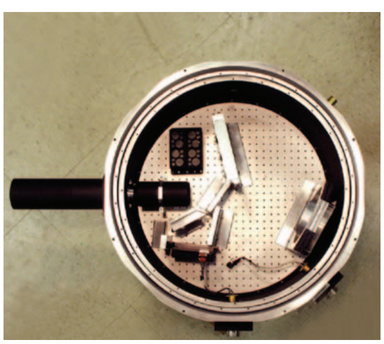
GOAL:

Enable a new science measurement capability or significantly improve the performance of an existing technique.

FY09 RESULT: Several ESTO projects satisfied this goal for FY09. Here are three notable examples:

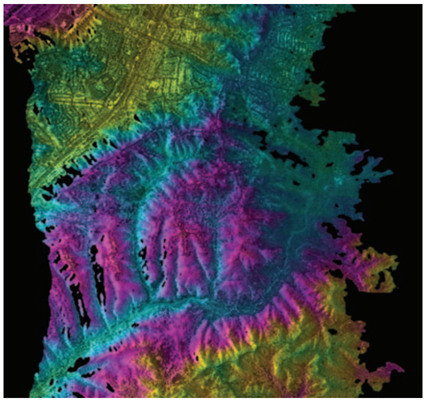
- The Slope Imaging Multi-polarization Photon-counting Lidar (SIMPL) instrument is a new prototype airborne altimeter developed to obtain precise elevation and depolarization data of ice sheets, sea ice, and land surfaces at 532 nm and 1064 nm. The 4-channel, photon-counting, polarimetric altimeter was built using many commercially available components and flew on several airborne test flights in October 2008 and February 2009. SIMPL's depolarization techniques allow for the identification of surface characteristics – snow, ice, water, land, etc – in addition to precise elevation measurements. *(Principal Investigator: David Harding, NASA Goddard Space Flight Center)*

Top: SIMPL being loaded onto the NASA Learjet 25 for the 2008 test flights. At left: integration above the aircraft viewport. (Image Credit: David Harding)



Above are optics hardware for the TIMS Instrument (Image Credit: John Kumer)

- Field tests of the Tropospheric Infrared Mapping Spectrometer (TIMS) instrument have demonstrated it can provide improved column CO measurements. TIMS can acquire radiance, at high spectral resolution, in the regions of the CO bands near 4.7 microns as well as near 2.3 microns, a new wavelength (shortwave infrared) measurement for tropospheric CO. These spectra contain information that could also be used to measure column CH4 and H2O partial columns. TIMS uses low noise 2D arrays fed by a grating spectrometer. There are no moving parts. The compact design was intended for LEO but many technologies could be useful for GEO missions such as GEO-CAPE. *(Principal Investigator: John Kumer, Lockheed Martin)*

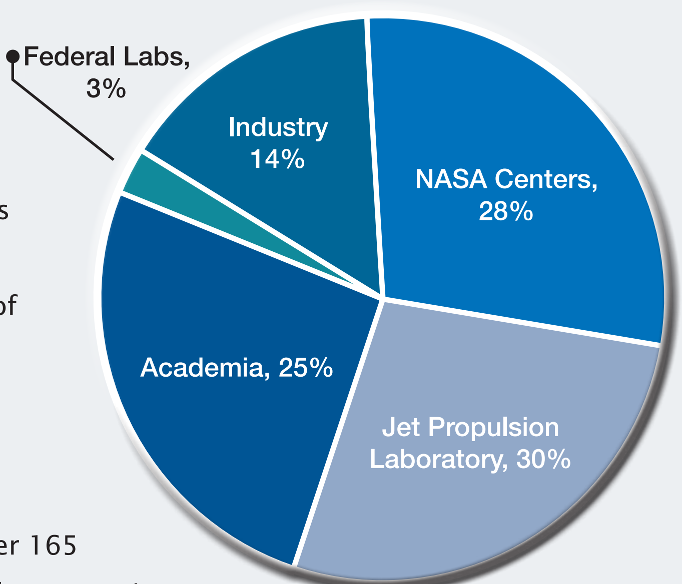


An image from the GLISTIN instrument taken during an engineering test flight over California. (Image Credit: Delwyn Moller)

- With two receiving antennas that are separated by about 10 inches, a novel, proof-of-concept Ka-band radar called the Glacier and Land Ice Surface Topography Interferometer (GLISTIN) uses millimeter-wave synthetic aperture radar interferometry technique to simultaneously generate both imagery and high-precision topographic maps of glaciers and ice sheets. Unlike the current microwave radars, the GLISTIN topographic measurements are significantly less susceptive to penetration biases. They are also less sensitive to cloud covers as compared to lidar topography measurements. In Spring 2009, GLISTIN flew on the NASA Gulfstream III aircraft over Greenland on a two-week campaign to evaluate tools and technologies for future space-based radars. *(Principal Investigator: Delwyn Moller, Jet Propulsion Laboratory)*

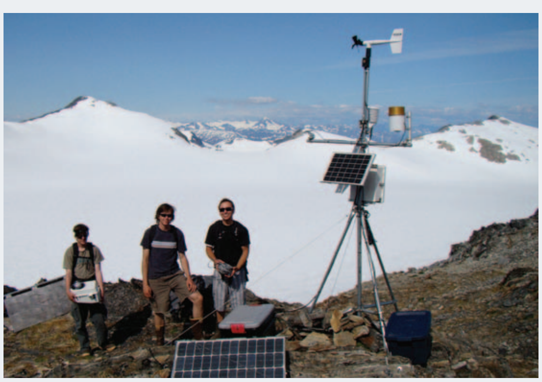
About ESTO Investigators

ESTO's 392 current principal investigators and co-investigators represent a diverse set of institutions – see graph at right. Over the past decade, ESTO PIs and Co-Is have performed technology development and research in nearly every state and the District of Columbia.



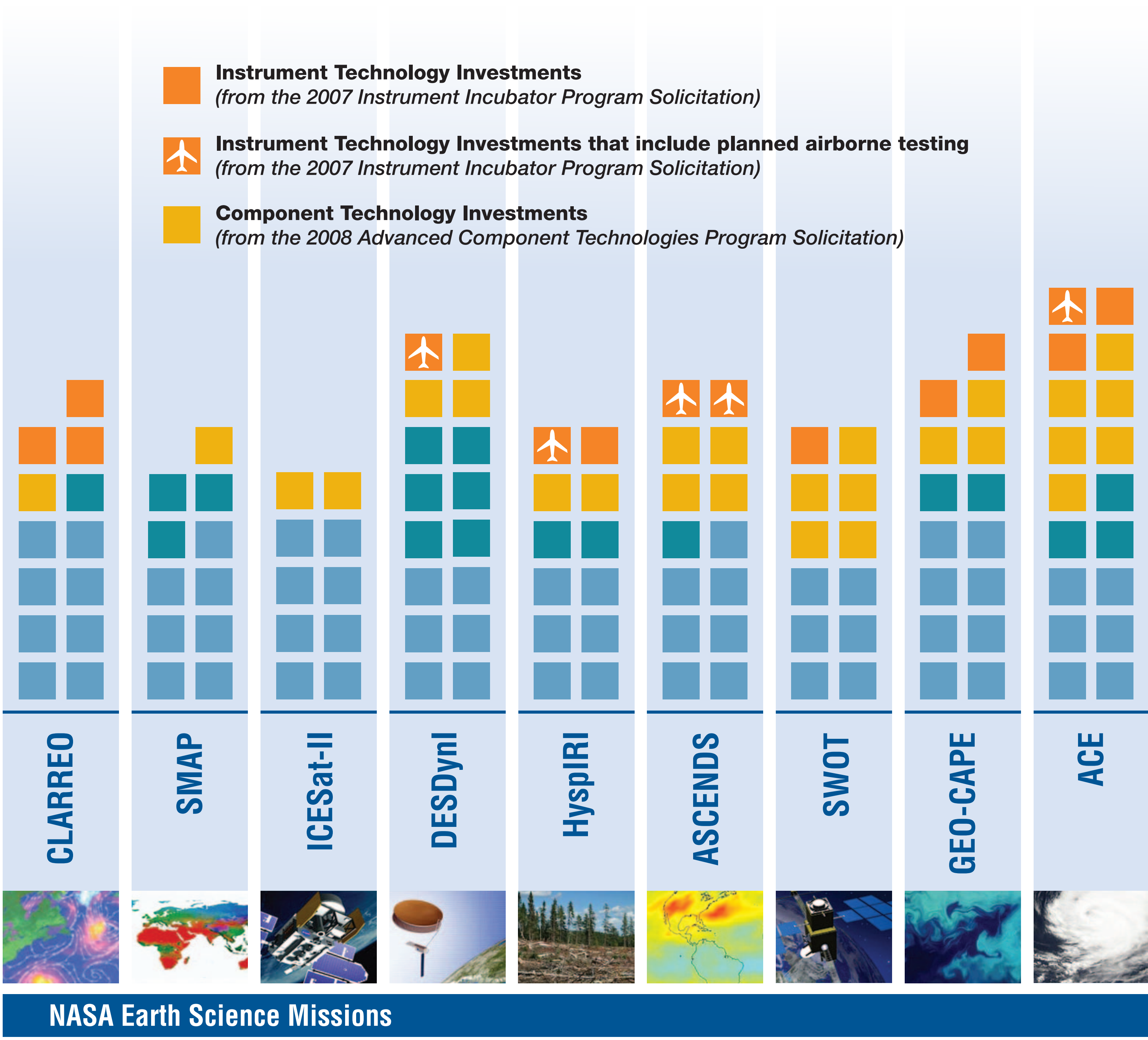
Student Participation

In 2009 alone, ESTO-funded projects supported over 165 students from 50 academic institutions. About half are pursuing doctorates and others are working toward masters or undergraduate degrees.

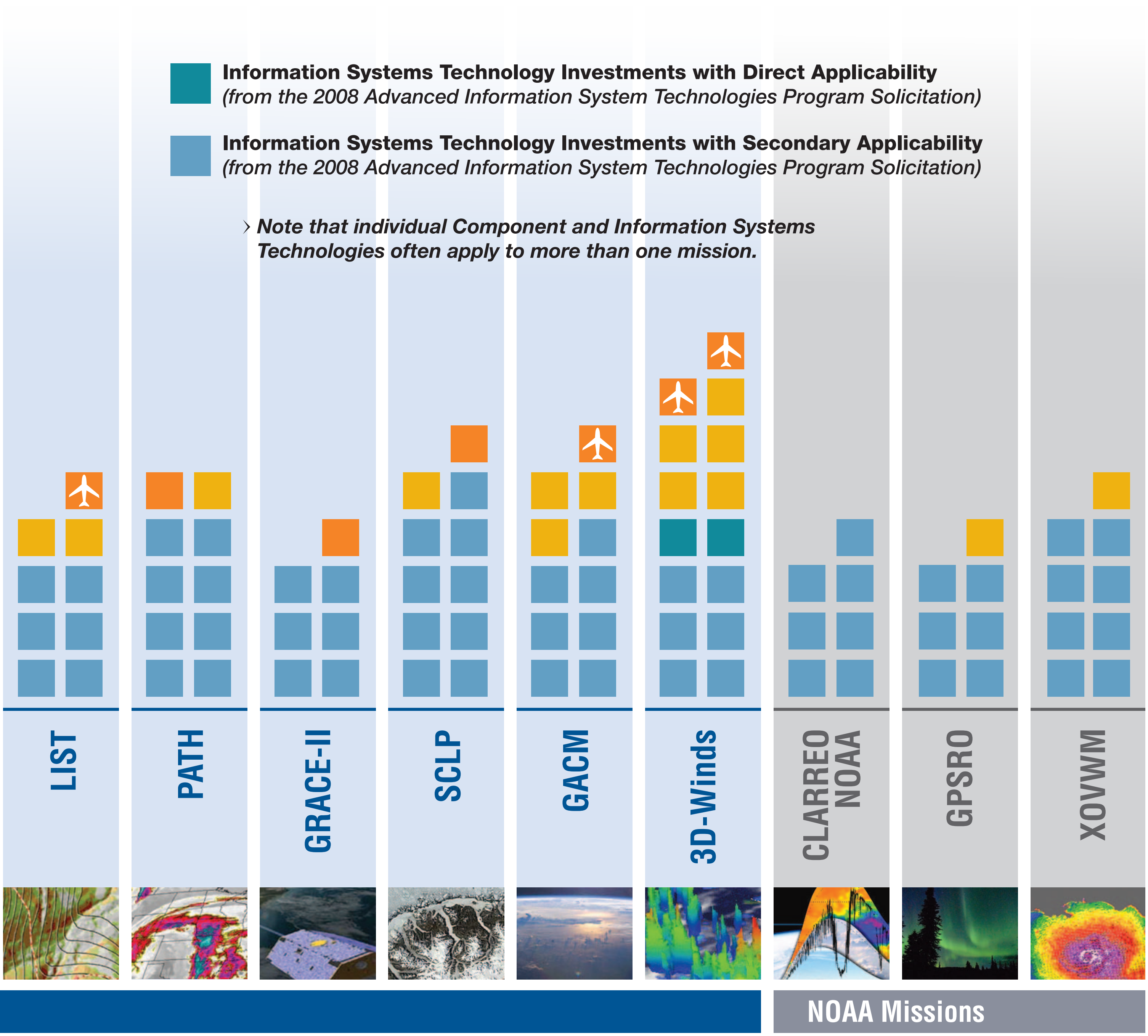


Toward the Decadal Survey

In 2007, the National Research Council (NRC) completed and released the first 10-year survey for Earth Science – *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*. Sponsored by NASA, NOAA and USGS, this Decadal Survey aids in the prioritization of research areas, observations, and the notional missions needed to realize those observations. At the time of publication, ESTO technology investments were already available to support all 18 of the recommended notional missions.



Since publication of the Decadal Survey, ESTO has made 58 additional investments – within our instruments, components, and information systems programs – that will further support and enable these measurement goals. The table below shows the distributed applicability, by technology investment area, of these new ESTO projects to the Decadal Survey missions. An interactive version of this table that includes specific investment information can be found on the ESTO website: esto.nasa.gov

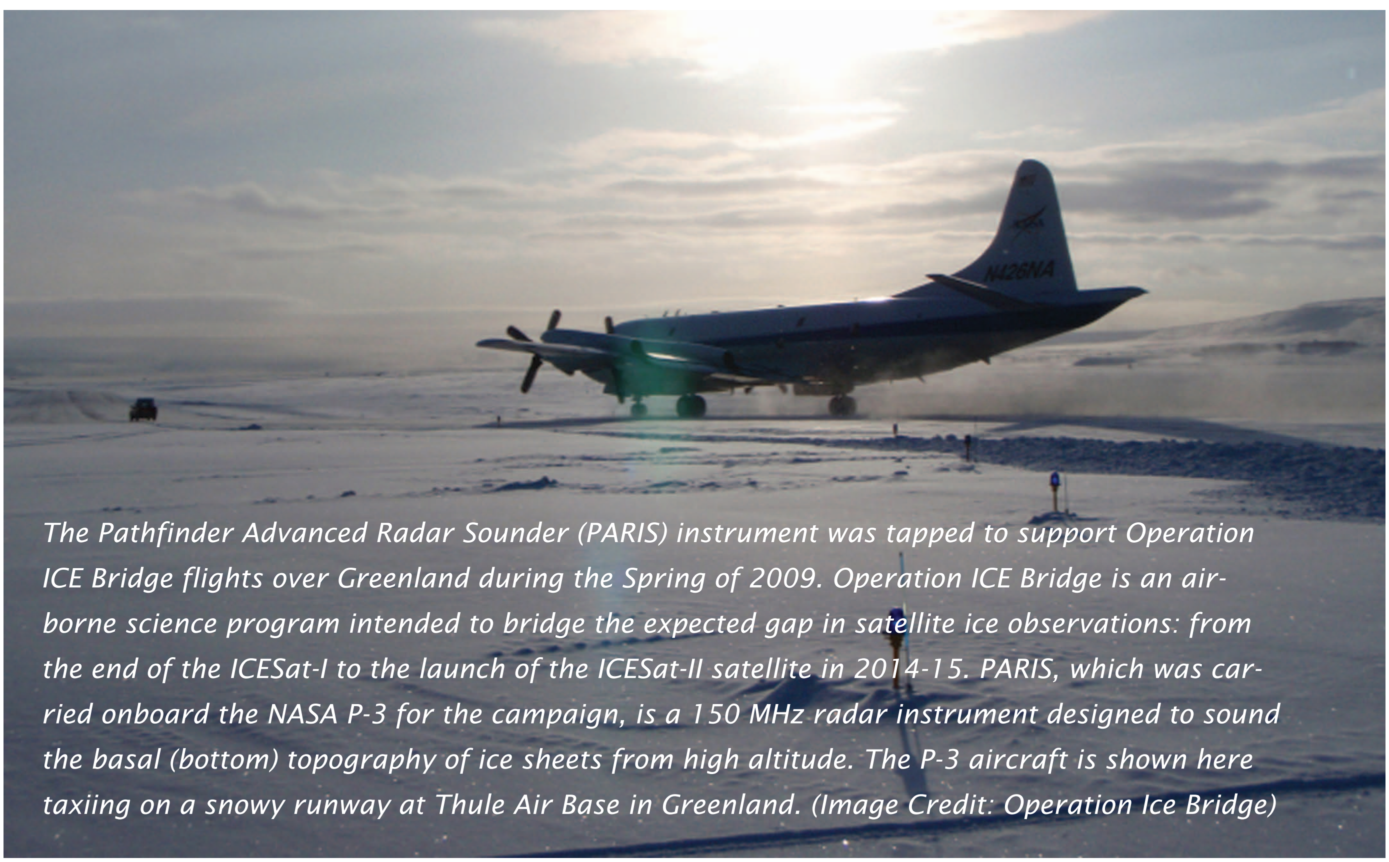


2009 in Review: **Instruments**

The Instrument Incubator Program (IIP) provides funding for new instrument and measurement techniques, from concept development through breadboard and flight demonstrations. Instrument technology development of this scale outside of a flight project consistently leads to smaller, less resource intensive, and easier to build flight instruments. Furthermore, developing and validating these technologies before mission development improves their acceptance and infusion by mission planners and significantly reduces costs and schedule uncertainties.

The IIP held some 44 active projects in FY09, 21 of which were added in April 2008 through a competitive solicitation that was broadly aimed at addressing the science measurement objectives put forward by the National Research Council Decadal Survey. The IIP also graduated 19 projects in FY09. Of these graduates, 14 advanced at least 1 TRL during the course of funding.

Above, the UAVSAR (Uninhabited Aerial Vehicle Synthetic Aperture Radar) pod below the NASA Gulfstream III aircraft. Developed with ESTO funding, UAVSAR is now a fully-operational airborne instrument for surface deformation measurements. ESTO is currently conducting studies to integrate the technology onto the Global Hawk UAV platform. (Image Credit: Dave Bullock, Wired.com)



The Pathfinder Advanced Radar Sounder (PARIS) instrument was tapped to support Operation ICE Bridge flights over Greenland during the Spring of 2009. Operation ICE Bridge is an airborne science program intended to bridge the expected gap in satellite ice observations: from the end of the ICESat-I to the launch of the ICESat-II satellite in 2014-15. PARIS, which was carried onboard the NASA P-3 for the campaign, is a 150 MHz radar instrument designed to sound the basal (bottom) topography of ice sheets from high altitude. The P-3 aircraft is shown here taxiing on a snowy runway at Thule Air Base in Greenland. (Image Credit: Operation Ice Bridge)

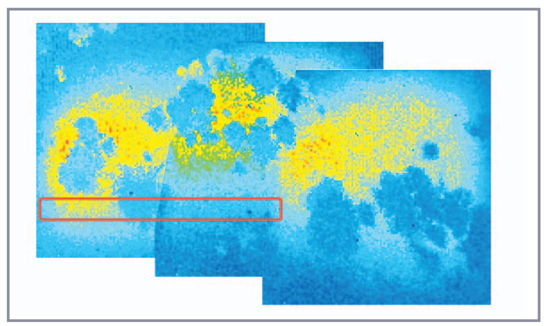
SPOTLIGHT: Flash LIDAR Shows Promise for Vegetation Measurements

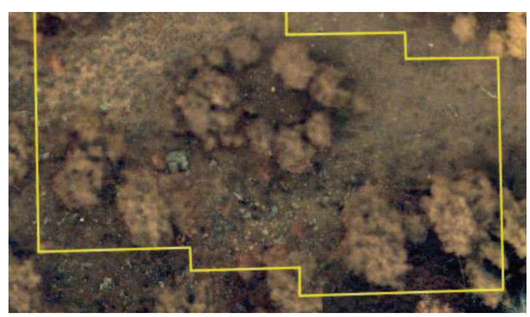
In October 2008, a prototype Flash LIDAR instrument flew on a series of airborne tests to demonstrate its potential for improved vegetation measurements. The prototype is a precursor to the Electronically Steerable Flash LIDAR (ESFL) currently under development at Ball Aerospace and Technology Corporation with funding from the NASA Earth Science Technology Office. ESFL may soon significantly expand our ability to measure vegetation and forests and better understand the extent of their role in global climate change and the carbon cycle.

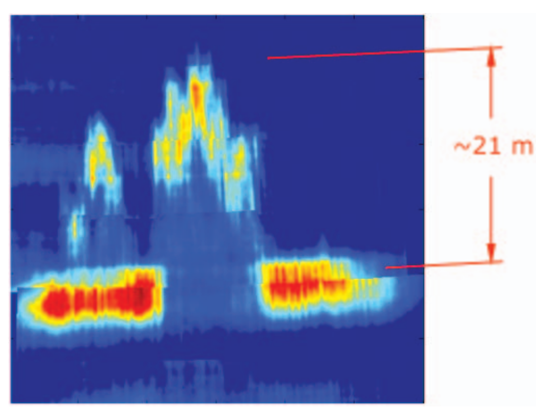
Unlike today's LIDAR instruments, the ESFL system using a single laser to create multiple beams that can instantaneously sample numerous cross-track ground footprints. This approach provides a traditional 2-dimensional intensity measurement combined with a range (distance) measurement to produce a 3-dimensional view of vegetation that shows height, density, and shape. The multiple beams are also independently and non-mechanically controllable and steerable, allowing for a variety of footprint coverage options – from closely packed to broadly spaced out – to match the science goals.

This type of measurement could help scientists answer a wide range of pressing questions: How much carbon is stored (sequestered) in a particular forest? What are the global effects of land use change and deforestation on atmospheric carbon dioxide? Is the foliage in a given area concentrated near the ground, at the tree canopy, or vertically distributed? How would a forest fire progress? An ESFL-type instrument could even address questions related to biodiversity: "Certain types of birds will only nest in certain trees or at certain heights," said ESFL Principal Investigator, Carl Weimer. "With a 3-D view, we'd be able to determine whether those habitats exist in particular areas based on the shape and height of the trees."

At present, the team is comparing the airborne data with ground-truth measurements and continuing to develop and integrate several critical components for the final ESFL system. More airborne tests are planned in early FY10.







At right are images collected during the test flights from 250 m over a prescribed burn site in Colorado. At the top is a mosaic of the LIDAR intensity return (trees appear as shadows). The middle image was taken concurrently with a visible camera and the outline of the LIDAR image area is indicated in yellow. The red box in the top image indicates the approximate area of the vertical profile shown at the bottom. (Image Credit: Carl Weimer, Principal Investigator)

2009 has seen a dramatic increase in "major blowouts" of water mains in Los Angeles – above: a water main break on Coldwater Canyon Avenue which later caused a sinkhole. The L.A. Department of Water and Power has asked scientists, including Andrea Donnellan with the AIST-funded QuakeSim project, to evaluate the possibility that seismic activity might be the cause of the increase. Although the QuakeSim team is still analyzing seismic data and water main break locations, Donnellan has reported "some deviation from the normal range ground movement." (Image Credit: Irfan Khan / Los Angeles Times)

Advanced information systems are used to process, archive, access, visualize, communicate, and understand science data. Advanced computing and communications concepts that permit the transmission and management of terabytes of data are essential to NASA's vision of a virtually unified observational network. ESTO's Advanced Information Systems Technology (AIST) program employs an end-to-end approach to evolve these critical technologies – from the space segment, where the information pipeline begins, to the end user, where knowledge is advanced.

The AIST program held 51 active investments in FY09, 20 of which were added in December 2008 through a competitive solicitation that sought technology development activities leading to new systems for sensor support, advanced data processing, and management of data services. These new projects are:

- **Real-Time In Situ Measurements for Earthquake Early Warning and Spaceborne Deformation Measurement Mission Support**
- **Geostatistical Data Fusion for Remote Sensing Applications**
- **QuakeSim: Accessibility and Utility of Earthquake Fault Data**
- **Advanced Hybrid On-Board Data Processor - SpaceCube 2.0**
- **Autonomous, On-board Processing for Sensor Systems**
- **Technology Infusion for the Real Time Mission Monitor**
- **Real-Time and Store-and-Forward Delivery of Unmanned Airborne Vehicle Sensor Data**
- **Multi-Sensor Data Synergy Advisor**
- **Onboard Processing and Autonomous Data Acquisition for the DESDynI Mission**
- **Sensor Web 3G to Provide Cost-Effective Customized Data Products for Decadal Missions**
- **Ground Network Design & Dynamic Operation for Validation of Space Soil Moisture Measurements**
- **Anomaly Detection and Analysis Framework for Terrestrial Observation and Prediction System (TOPS)**
- **On-Board Processing for the MSPI Imaging System on ACE**
- **Integration of Data Assimilation, Stochastic Optimization, and Uncertainty Modeling within NASA LIS**
- **InSAR Scientific Computing Environment**
- **Moving Objects Database Technology for Weather Event Analysis and Tracking**
- **End-to-End Design and Objective Evaluation of Sensor Web Modeling and Data Assimilation Architectures**
- **Coupling Multi-scale Modeling and Concurrent Visualizations for Improved Predictions of Tropical High-impact Weather**
- **Instrument Simulator Suite for Atmospheric Remote Sensing**
- **OSCAR: Online Services for Correcting Atmosphere in Radar**

AIST also graduated 14 projects over the course of FY09, 12 of which advanced at least one TRL during the course of funding.

SPOTLIGHT: Sensor Web Technology Aids Volcano Monitoring Effort

On July 14, 2009, several "spider" pods like the one shown above were lowered by cable from a helicopter hovering about 100 feet up and gently put in hot spots inside and around the volcano crater of Mt. St. Helens. (Image Credit: Willie Scott / USGS)

In a collaborative effort between USGS, NASA, and Washington State University Vancouver, high-tech "spider" pods were placed inside and around the mouth of Mount St. Helens to create a network that could one day be used to respond rapidly to an impending eruption. The fifteen pods form a virtual wireless network, communicating with each other and the Earth Observing-1 (EO-1) satellite, which can be triggered to take observations from space.

"This project demonstrates that a low-cost sensor network system can support real-time monitoring in extremely challenging environments," said WenZhan Song of Washington State University Vancouver. Song is the principal investigator for an AIST-funded project tasked with developing the autonomous networking software.

The spiders were built to operate in extreme temperatures and treacherous terrain. Each pod contains a seismometer to detect earthquakes; a GPS receiver to pinpoint the exact location and measure subtle ground deformation; an infrared sounder to sense volcanic explosions; and a lightning detector to search for ash cloud formation. The main instrument box is the size and shape of a microwave oven. It sits on top of a three-legged tripod, which is why scientists call them spiders. The pods are powered by batteries that can last for at least a year.

The network of pods can supply long-term data without endangering researchers as well as quickly provide valuable real-time information to emergency services in the event of an eruption. "We hope this network will provide a blueprint for future networks to be installed on many of the world's unmonitored active volcanoes," said Sharon Kedar of the Jet Propulsion Laboratory.

This work is one of several AIST-funded projects that are developing sensor webs to provide timely data and analyses for scientific research, natural disaster mitigation, and the exploration of hazardous environments.

2009 in Review: **Components**

The Advanced Component Technology (ACT) program leads research, development, and testing of component- and subsystem-level technologies for future state-of-the-art Earth science instruments and instrument systems. The ACT program focuses on projects that reduce risk, cost, size, mass, and development time of technologies to enable their eventual infusion into missions.

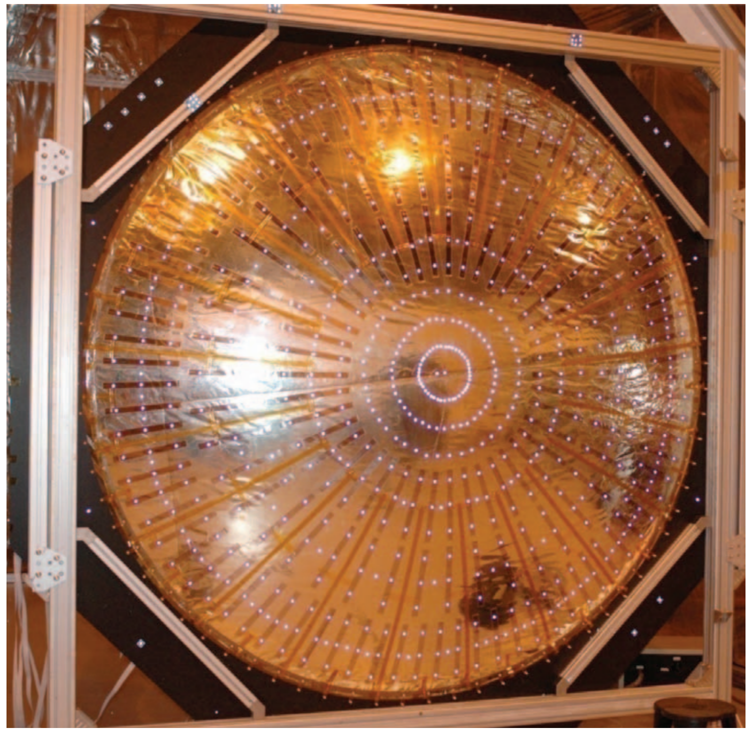
In FY09, the ACT program portfolio held a total of 28 investments. 16 of these projects were added in November 2008 through a competitive solicitation that sought component technologies in four broad areas – active optical, passive optical, microwave, and calibration for radiation measurements. These new projects are:

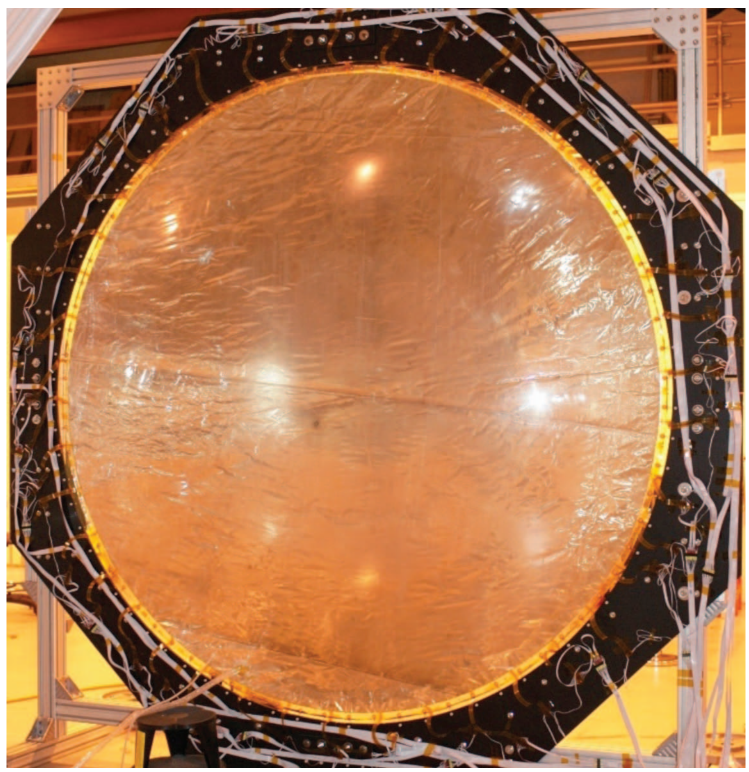
- **A Low Cost, Lightweight Corrugated Mirror Telescope Array for Lidar and Passive Earth Science Missions**
- **A Large High-Precision Deployable Reflector for Ka- and W-band Earth Remote Sensing**
- **Advanced Thermal Packaging Technologies for RF Hybrids**
- **A Time-Domain Polarization Scrambler for Wavelength-Diverse Sensors**
- **Hybridized Visible-NIR Blind Focal Plane Arrays**
- **An Ultra-Sensitive Near-Infrared Optical Receiver Using Avalanche Photodiodes**
- **A Hybrid Doppler Wind Lidar Transceiver**
- **Detector Technology Development for Cloud-Aerosol Transport Lidar**
- **A GNSS Radio Frequency Hybrid Integrated Circuit For Digital Beamforming Applications**
- **Far-Infrared Extended Blocked Impurity Band Detectors Optimized for Earth Radiance Measurements**
- **CO2 Laser Absorption Spectroscopy Sensor Instrument Technology Maturation for ASCENDS**
- **Low-Mass, Low-Power High-Frequency Radiometers for Coastal Wet-Tropospheric Correction on SWOT**
- **An In-Pixel Digitization Read Out Integrated Circuit for the Geostationary Coastal and Air Pollution Events (GEO-CAPE) Mission**
- **A Low Power, High Bandwidth Receiver for Ka-band Interferometry**
- **A Large Aperture, Solid Surface Deployable Reflector**
- **A Large, Deployable Ka-Band Reflectarray For The SWOT Mission**

These projects have the potential for significant advancement in the technology readiness of the Earth science measurements recommended by the NRC Decadal Survey. The ACT program also graduated 11 projects in FY09, 9 of which advanced at least one TRL over their course of funding.

At left is a fully assembled brassboard of a 230-GHz superconductor-insulator-superconductor (SIS) receiver for microwave limb sounding. Wide bandwidth microwave limb sounders can provide accurate, simultaneous measurements of more than a dozen important molecules in the upper troposphere and stratosphere. This advanced technology receiver achieves twenty times the sensitivity of the limb sounder receivers employed on Aura and may contribute significantly to the Global Atmospheric Composition Mission. The receiver will be used immediately in a recently-selected ESTO IIP task – "A Scanning Microwave Limb Sounder for Studying Fast Processes in the Troposphere" – as well as in existing ground and balloon instruments. (Image Credit: Karen Lee, Principal Investigator)

SPOTLIGHT: A Precise Control System for Large Antenna Surfaces





The "High-Precision Adaptive Control of Large Antenna Surface" ACT technology development task (principal investigator: Houfei Fang) sought to develop a high-precision adaptive control system to correct the surface distortions in large, deployable, membrane antennas. Large, space-deployable antennas are a critical technology for future remote sensing systems at medium- or geosynchronous-Earth orbit (GEO) to provide detailed monitoring of Earth's resources, weather, and climate. Ensuring that a large flexible antenna can maintain the correct shape and figure once deployed in space is a key challenge.

The adaptive control system developed and tested under this task utilized several state-of-the-art technologies, include Flexible PVDF (Poly-Vinylidene Fluoride) Polymer Film actuators, an advanced membrane reflector, wavefront sensing metrology, and active shape control laws. These individual technologies will contribute significantly toward the development of a new generation of large, lightweight membrane antennas.

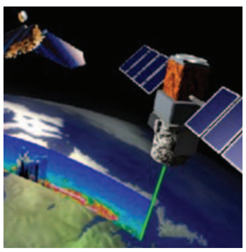
At right are the back (top) and front (bottom) of a fully-assembled 2.4 meter reflector. 168 actuators in three rings are visible on the back of the antenna as are 735 retroreflective targets.

Performance analyses conducted on this breadboard antenna correlated well with the experimental data and suggest that it would be feasible to scale up to a larger antenna (as large as 35 m) and achieve the required surface precision for GEO. At the time of publication, this breadboard antenna is considered the first demonstration of an actively controlled inflatable membrane antenna of this size. (Image Credit: Houfei Fang, Principal Investigator)

Future Challenges

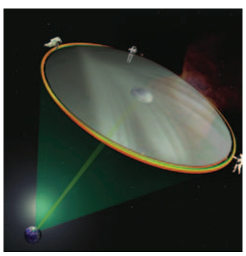
ESTO investments have, for many years, been buying down the risk of nearly all of the measurements recommended by the Decadal Survey. This is a testament to ESTO's best practices for technology development: competitive, peer-reviewed solicitations; active technology management; and broad-based, inclusive strategic planning. ESTO continues to monitor, and match investments to, the evolving needs of Earth science through engagement with the science community, development of technology requirements, and strategic planning for long-term investments.

In addition to established science measurement goals laid out in the NRC Decadal Survey and other strategic planning documents, ESTO has identified four broad areas that have the capacity to expand and support a multitude of Earth science disciplines:



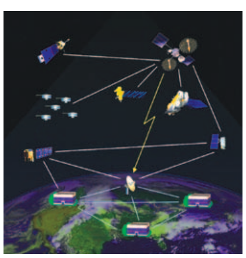
Active Remote Sensing Technologies to enable measurements of the atmosphere, hydrosphere, biosphere, and lithosphere.

- Atmospheric chemistry using lidar vertical profiles
- Ice cap, glacier, sea ice, and snow characterization using radar and lidar
- Tropospheric vector winds using lidar



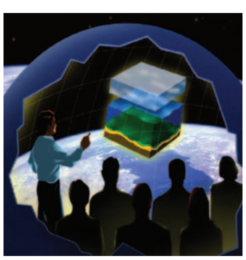
Large Deployable Apertures to enable future weather, climate, and natural hazards measurements.

- Temperature, water vapor, and precipitation from geostationary orbit
- Soil moisture and sea surface salinity using L-band
- Surface deformation and vegetation using radar



Intelligent Distributed Systems using advanced communication, on-board radiation-tolerant reprogrammable processors, autonomous operations and network control, data compression, high density storage.

- Long-term weather prediction linking observations to numerical models
- Interconnected sensor webs that share information to enhance observations



Information Knowledge Capture through novel visualizations, memory and storage advances, and seamlessly linked models.

- Intelligent data fusion to merge multi-mission data
- Discovery tools to extract knowledge from large and complex data sets
- Real time science processing, archiving, and distribution of user products to drive decision support systems

Additional Resources

A wealth of additional materials is available online at the ESTO home page – http://esto.nasa.gov – including:

More about ESTO's approach to technology development, ESTO programs, and strategic planning

An interactive tool that shows ESTO's linkages to the NRC Decadal Survey

Information about ESTO solicitations and awards

A compilation of useful reports, presentations, and other documents on technology development for NASA Earth science

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