National Aeronautics and Space Administration

YEAR

Earth Science Technology Office

2008 annual report

Executive Summary

This year, the NASA Earth Science Technology Office (ESTO) celebrates its decadal anniversary. We take great pride in the efforts and accomplishments of the many projects we have funded and managed over the past 10 years. In this special 10th anniversary annual report, we take a look back at some of those accomplishments, highlight Fiscal Year 2008 (FY08) progress, and look forward to the future challenges for technology development for the Earth sciences.

FY08 has been another productive year for ESTO. Activities have focused on guidance provided by the National Research Council (NRC) of the National Academies, in the first-ever decadal survey for Earth science: "Earth Science and Applications from Space." We are pleased to note that ESTO technologies are directly applicable to every mission outlined by this decadal survey.

Twenty one new projects were awarded funding under an Instrument Incubator Program (IIP) solicitation, bringing the total ESTO portfolio to more than 535 active and completed technology investments. Solicitations were also released by the Advanced Component Technologies (ACT) and Advanced Information Systems Technology (AIST) programs with awards expected in FY09.

ESTO also continues to build upon a strong history of technology infusion. In FY08 over 11% of active ESTO technology projects achieved actual infusion into science measurements, system demonstrations, or societal applications, and an additional 74% have a path identified for future infusion. For the whole of ESTO's portfolio, excluding active projects, the infusion rate is over 33%.

We continue to be very proud of the achievements of our principal investigators and the contributions they make to the future of Earth science, and look forward to another year of innovations in FY09.

George J. Komar **Amy Walton**

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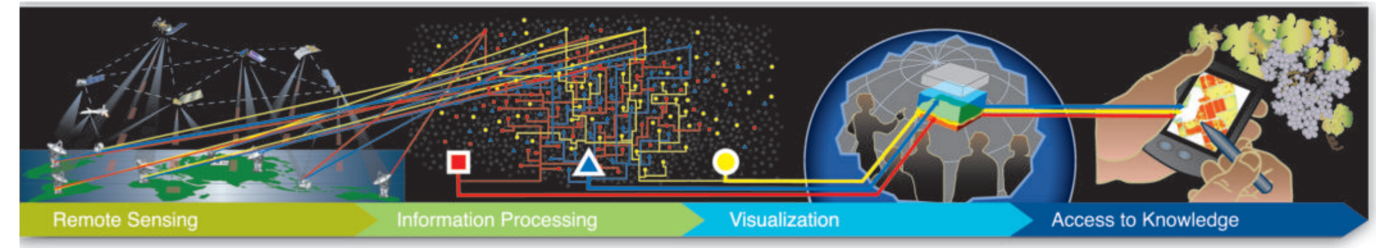


From instruments to data access, ESTO technologies enable a full range of scientific measurements

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
- Developing technologies through competitive solicitations and partnership opportunities
- Actively managing technologies throughout their course of funding
- Making technologies available to scientists and mission managers for infusion

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 varied portfolio of over 535 emerging technologies that can enable and/or enhance future science measurements and an ever-growing number of infusion successes.

2008 Metrics

Each dot represents one of the over 535 projects (active and completed) in ESTO's portfolio. ESTO's principal investigators hail from more than100 organizations in 32 states.

Co-investigators on these projects number well over 800 and represent nearly every state and the District of Columbia.

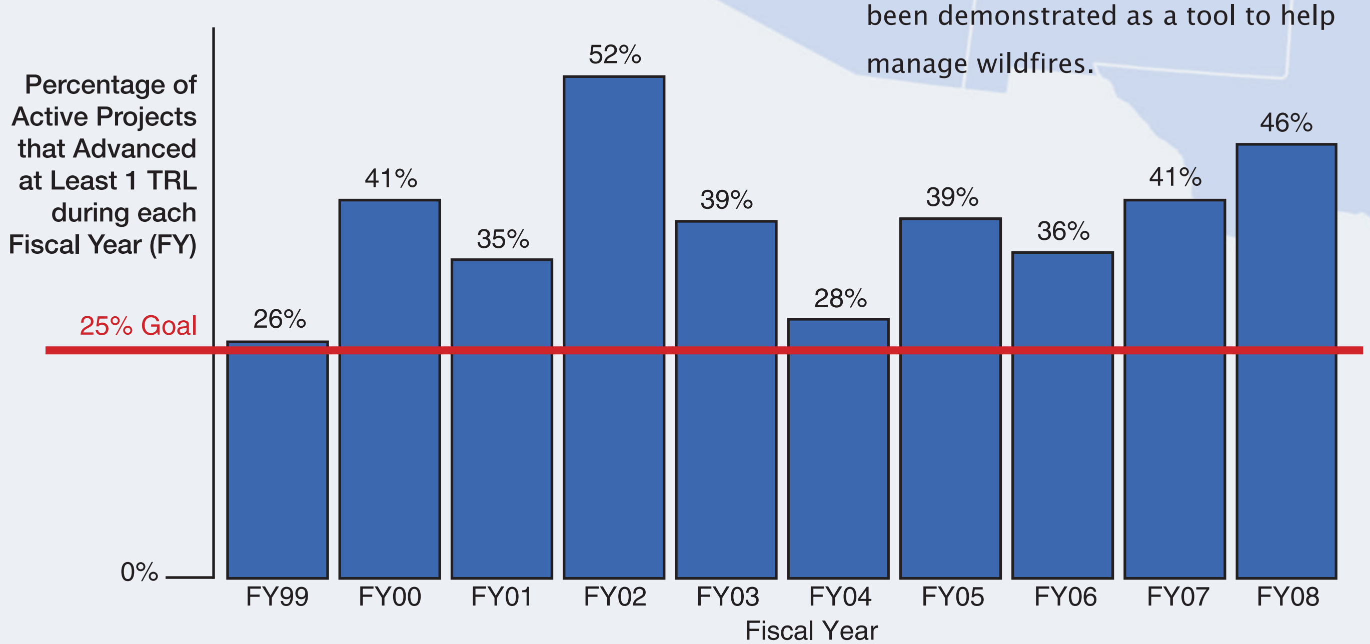
With more than 440 completed technology investments and a current, active portfolio of nearly 100 projects, ESTO is helping to build NASA's reputation for developing and advancing leading-edge technologies.

How did ESTO do this year?

Here are few of our successes for fiscal year 2008 (FY08), tied to NASA's performance goals for ESTO:

GOAL: Annually advance 25% of funded technology projects one Technology Readiness Level (TRL).

FY08 RESULT: 46.3% of currently funded technology projects advanced at least one TRL during FY08. See the graph below for yearly comparisons.



GOAL: Enable, or significantly improve the performance of, a science measurement capability.

FY08 RESULT: Several ESTO projects satisfied this goal for FY08. Here are two notable examples:

- The Raman Airborne Spectroscopic Lidar (RASL) instrument was flown several times on a KingAir aircraft in support of the Water Vapor Validation Experiments (WAVES) campaign and produced the first-ever simultaneous measurements of tropospheric water vapor mixing ratio and aerosol extinction from an airborne platform.

- An inter-operable sensor architecture system that integrates four satellites, a UAV, and multiple ground sensors, data algorithms, and models has been demonstrated as a tool to help manage wildfires.

SPOTLIGHT: ESTC2008

ESTO held its eighth-annual technology conference – the NASA Earth Science Technology Conference 2008 (ESTC2008) – June 2008 at the University of Maryland, College Park. The event showcased a wide array of technology research and development related to NASA's Earth science endeavors.

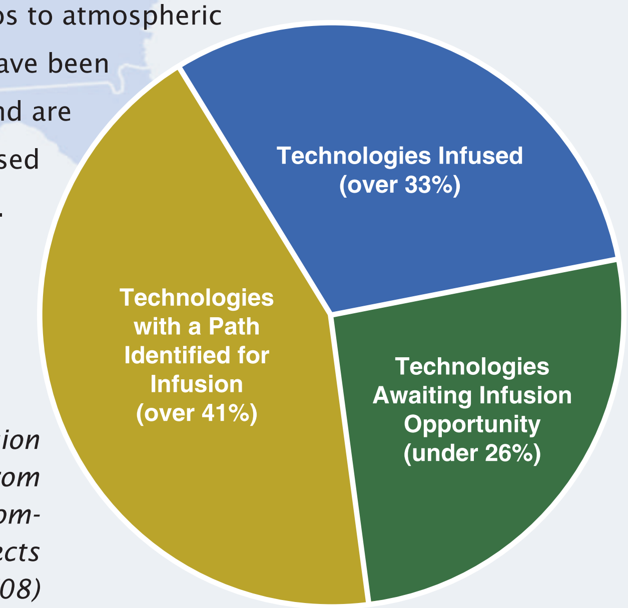
The agenda included nearly 60 technical papers in two parallel tracks of sessions. Luncheon talks were given by George Komar, Associate Director of Earth Science Technology, and Dr. Wayne Esaias, a biological oceanographer at NASA Goddard Space Flight Center. Attendees included a cross-section of representation from various NASA centers, industry, and academia. The full proceedings from ESTC2008, including abstracts and papers, are available at the ESTO website.

GOAL: Mature two to three technologies to the point where they can be demonstrated in space or in an operational environment.

FY08 RESULTS: Numerous ESTO projects achieved actual infusion in FY08. Two notable examples are:

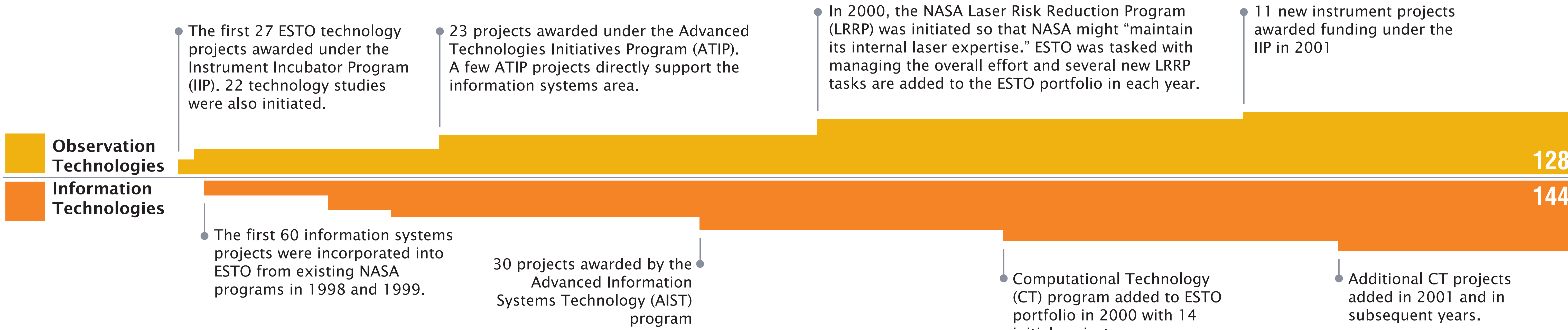
- The Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAV-SAR) project completed over 25 test flights in FY08. This L-Band radar instrument is able to measure millimeter-scale changes in the Earth's surface and will soon be available for science campaigns. See page 11 for additional information on the UAV-SAR project.

- The Semantically-Enabled Scientific Data Integration (SESDI) tool allows data from various sources to be easily accessed and understood using simple, plain-English queries. Several data sources covering various topics, from volcanos to atmospheric chemistry, have been registered and are now being used by scientists.



ESTO's Infusion Success (from over 440 completed projects through FY08)

10 Years of ESTO - A Special Anniversary Section



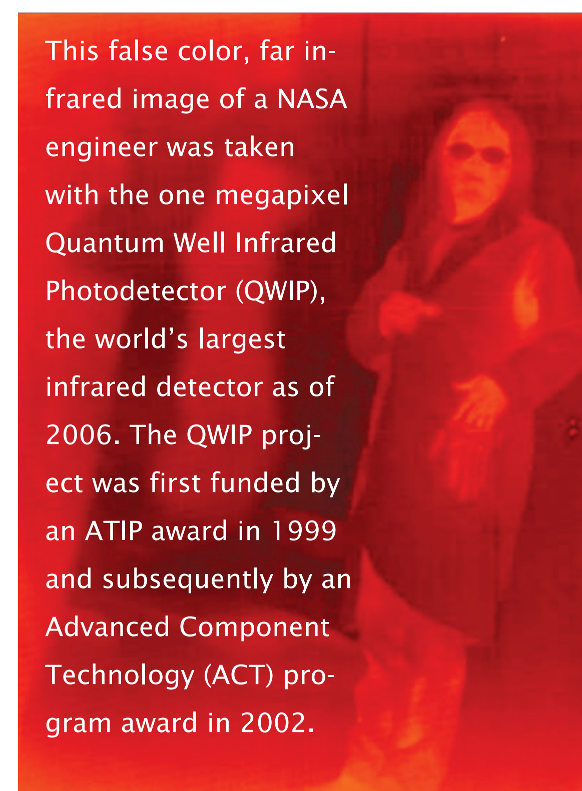
The above graph, which continues on following pages, shows the steady growth and progression of the ESTO portfolio of investments (active and completed projects) over the past 10 years.

1998 1999 2000 2001

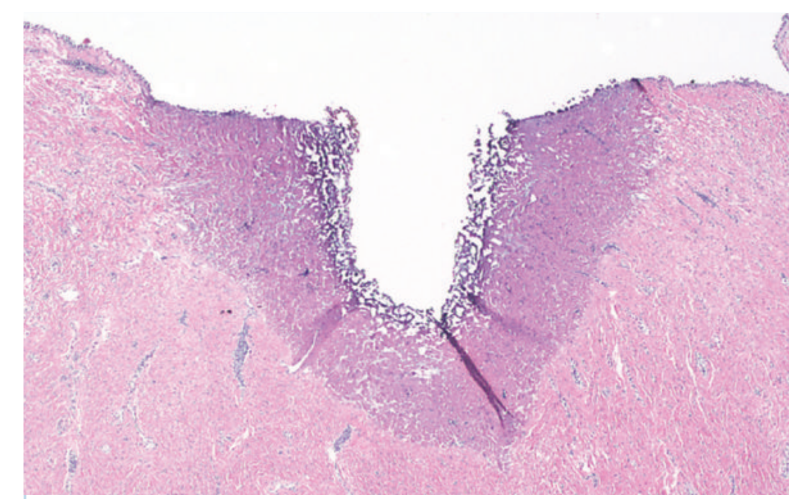
In June 1997, the report from a NASA Earth Science Biennial Review recommended that future Earth science missions be implemented with “shorter development time and using the best suitable technology.” To help meet this challenge, the Earth Science Technology Office (ESTO) was created in March of 1998 to fund and manage a broad portfolio of emerging technologies, based upon science measurement objectives, for infusion into a range of future campaigns and missions.

From the very beginning, ESTO has relied on free and open competition, a robust peer review process, and active project management to help guarantee that the best technologies are developed in a timely manner and made available to mission managers and scientists as needs arise.

The ESTO approach to technology development has proven very fruitful: more than one third of ESTO-funded technologies have already been infused into NASA missions or other applications and ESTO instrument investments support all of the missions outlined by the NRC Earth science decadal survey. What follows on the next few pages are a few examples of ESTO technology successes over the past 10 years.

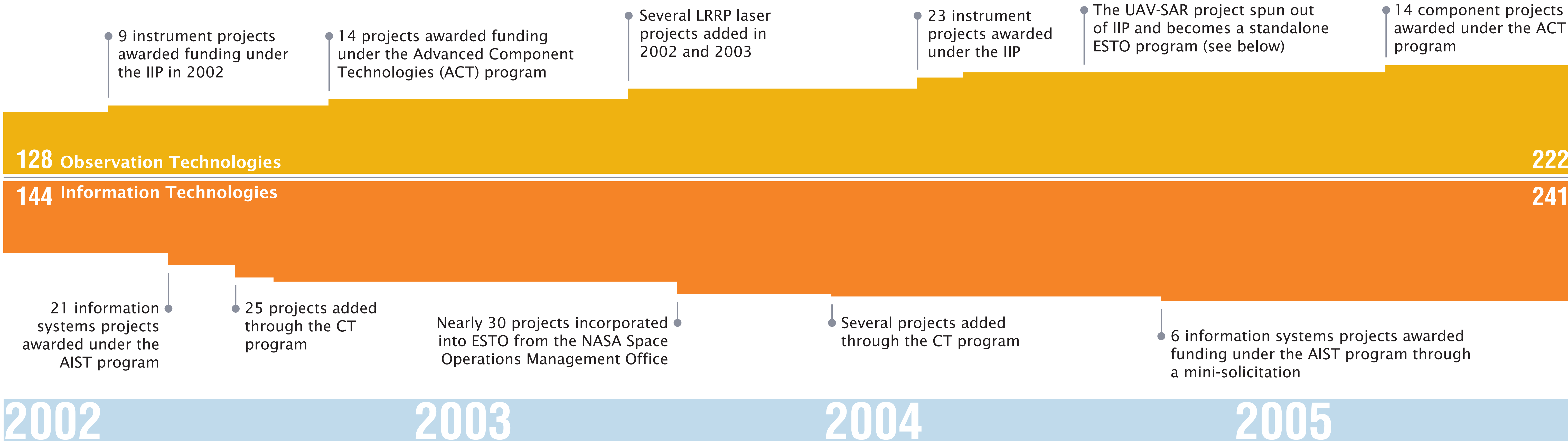


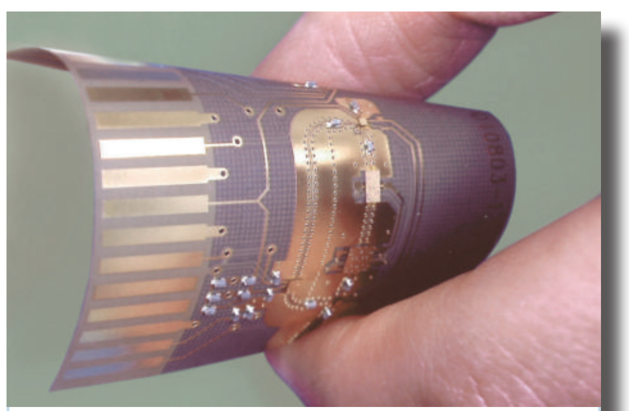
This false color, far infrared image of a NASA engineer was taken with the one megapixel Quantum Well Infrared Photodetector (QWIP), the world’s largest infrared detector as of 2006. The QWIP project was first funded by an ATIP award in 1999 and subsequently by an Advanced Component Technology (ACT) program award in 2002.



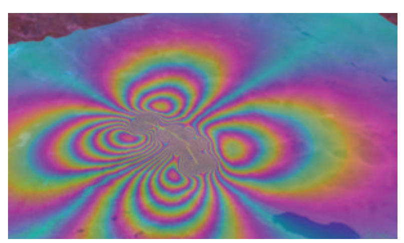
The Laser Risk Reduction Program has produced leading-edge laser technologies for NASA as well as for use in spin-off applications. This image shows a clean, distinct cut made in human tissue by an LRRP-funded, eye-safe, 40 watt, 1.94 micron Thulium fiber laser that has shown promise for use in medical procedures.

10 Years of ESTO - A Special Anniversary Section





This flexible Transmit / Receive (T/R) module was developed under an ACT-funded task that sought to advance the state-of-the-art technologies for large aperture scanning antennas. By integrating the T/R components directly onto a flexible membrane, a large antenna might be rolled or folded for launch and deployed in space.



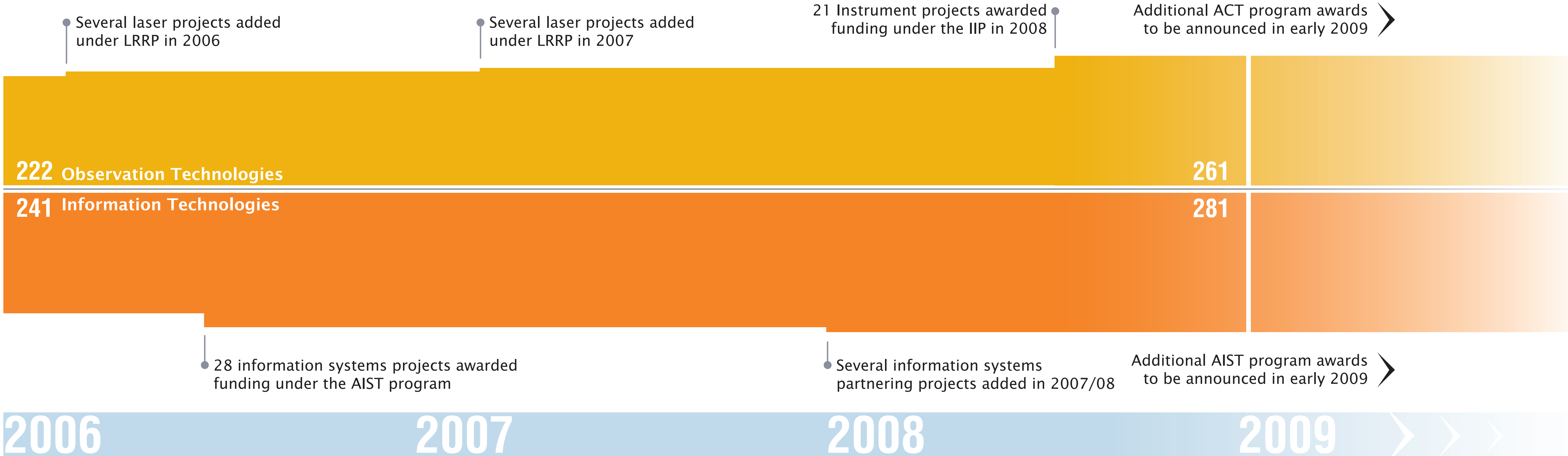
This interferogram of the 1992 Landers, California, earthquake was produced by the GeoFEST finite element model, a QuakeSim modeling environment.

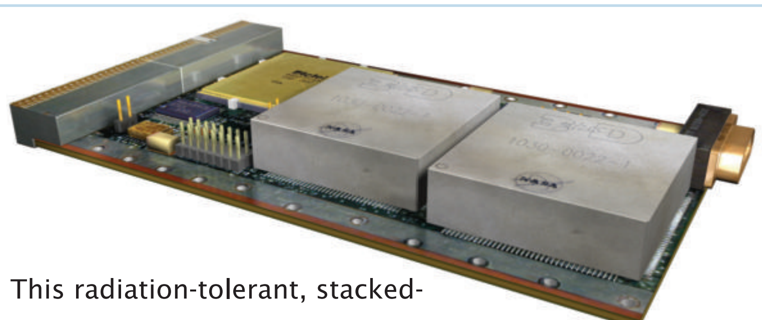
The QuakeSim project, funded by the AIST program beginning in 2003, developed a solid Earth science framework for modeling and understanding earthquake and tectonic processes. The project focused on integrating various data sources and models within a web-based portal that led to significant improvements in earthquake forecasting. In fact, by 2004 a model developed using the QuakeSim technology accurately forecast 15 of California's 16 largest earthquakes for the decade. Today, QuakeSim is providing critical design and science infrastructure support to the NASA DESDynI mission

In 2004, a promising IIP technology for surface deformation measurements from an airborne platform was tapped by NASA for further development. This project became the Uninhabited Aerial Vehicle - Synthetic Aperture Radar (UAV-SAR) program within ESTO and by 2008, the instrument was flying regularly on demonstration missions. (See p.11 for an FY08 update)

The IIP-funded FIRST (Far Infrared Spectroscopy of the Troposphere) instrument was successfully demonstrated in 2005 on a high-altitude research balloon flight over Ft. Sumner, NM. FIRST provided the first-ever infrared emission spectrum of the Earth in the 10-100 micron range, a spectral region that contains over 50% of Earth's longwave radiation.

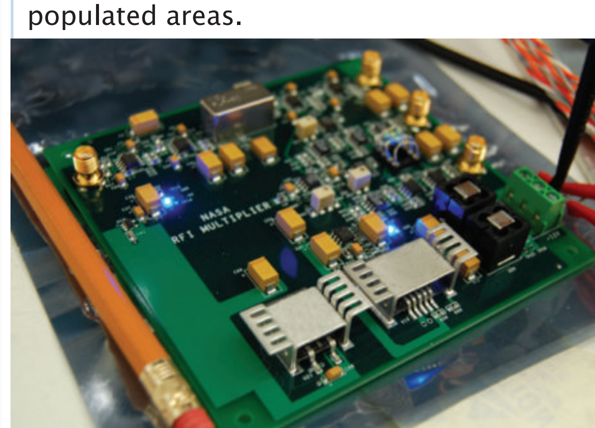
10 Years of ESTO - A Special Anniversary Section





This radiation-tolerant, stacked-memory array, developed with AIST funding in 2006, is suitable for both geostationary and low Earth orbit missions. The array is designed for high performance space-based computing applications, including: real-time data processing, reconfigurable computing, and other memory-intensive systems. With 2 Gigabits of error-corrected memory and weighing only 60 grams, this technology enables new measurement scenarios and reduces the risk, cost, size, and development time of future space-based systems.

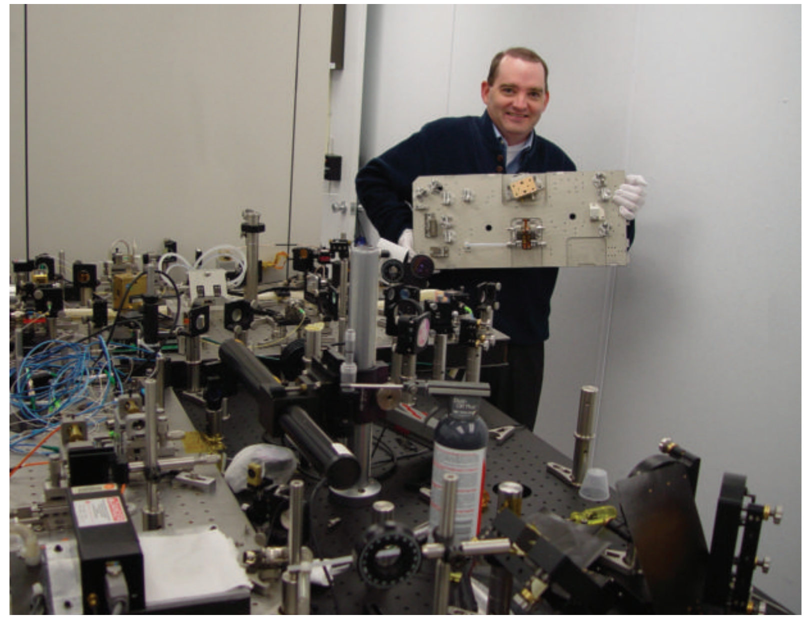
Funded by the ACT program from 2005 to 2008, this radio frequency interference (RFI) suppression system may soon be key to clearer microwave radiometer measurements from space, particularly as wireless communications and other services proliferate and crowd the spectrum over heavily populated areas.



In 2007, the IIP-funded Pathfinder Airborne Radar Ice Sounder (PARIS) completed 10 days of test flights on board the NASA P-3 aircraft and collected more than 900 GB of data over northern Greenland. As it was designed and developed to do, the 150 MHz radar instrument successfully sounded, from high altitude, the internal layering and bottom (basal) topography of the Greenland ice sheet along the flight routes. The demonstration represents a large step toward a future space-based radar system for Earth's ice sheets.

2008 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 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.



Before and After: The IIP-funded Doppler Aerosol WiND Lidar (DAWN) project is developing and packaging 2-micron laser components into an instrument system capable of coherent wind measurements in support of the proposed 3D Winds NRC decadal survey mission. The photo above shows a program technologist, Grady Koch of NASA Langley Research Center, giving visual aid to a remarkable reduction in the size of the DAWN transmitter – from the entire benchtop breadboard in the foreground (approximately 4 x 8 feet) to the packaged system held by Grady. The package was significantly ruggedized as well. The project team was recently awarded new funding by the IIP for further development and high altitude aircraft demonstrations.

The IIP held some 45 active projects in FY08, 21 of which were added during the year through a competitive solicitation that was broadly aimed at addressing the science measurement objectives put forward by the National Research Council decadal survey. These new projects are:

- **CO2 Laser Sounder for ASCENDS**
- **Shortwave Infrared Polarimetric Imager**
- **Infrared Correlation Radiometer**
- **Laser Ranging Frequency Stabilization Subsystem for GRACE II**
- **Ka-band SAR Interferometry Studies**
- **An Optical Autocovariance Direct Detection Wind Lidar**
- **Thermal Infrared Imaging Spectrometer**
- **Laser Approach for CO2 Columns**
- **Hyperspectral Thermal Emission Spectrometer for HyspIRI-TIR Science**
- **Airborne Demonstration of an Autonomous Operation Coherent Doppler Lidar (DAWN Air II)**
- **Hyperspectral Imager to Meet CLARREO Goals of High Absolute Accuracy and On-Orbit Traceability**
- **GeoSTAR technology development**
- **Ocean Radiometer for Carbon Assessment (ORCA) Prototype**
- **Electronically Steerable Flash Lidar**
- **Scanning Microwave Limb Sounder**
- **Calibrated Observations of Radiance Spectra**
- **A Multi-parameter Atmospheric Profiling Radar for ACE**
- **Lightweight, 3-D Integrated X-Band Radar**
- **Advanced Accuracy Satellite Instrumentation**
- **Panchromatic Fourier Transform Spectrometer (PanFTS)**
- **Efficient Swath Mapping Laser Altimetry Demonstration**

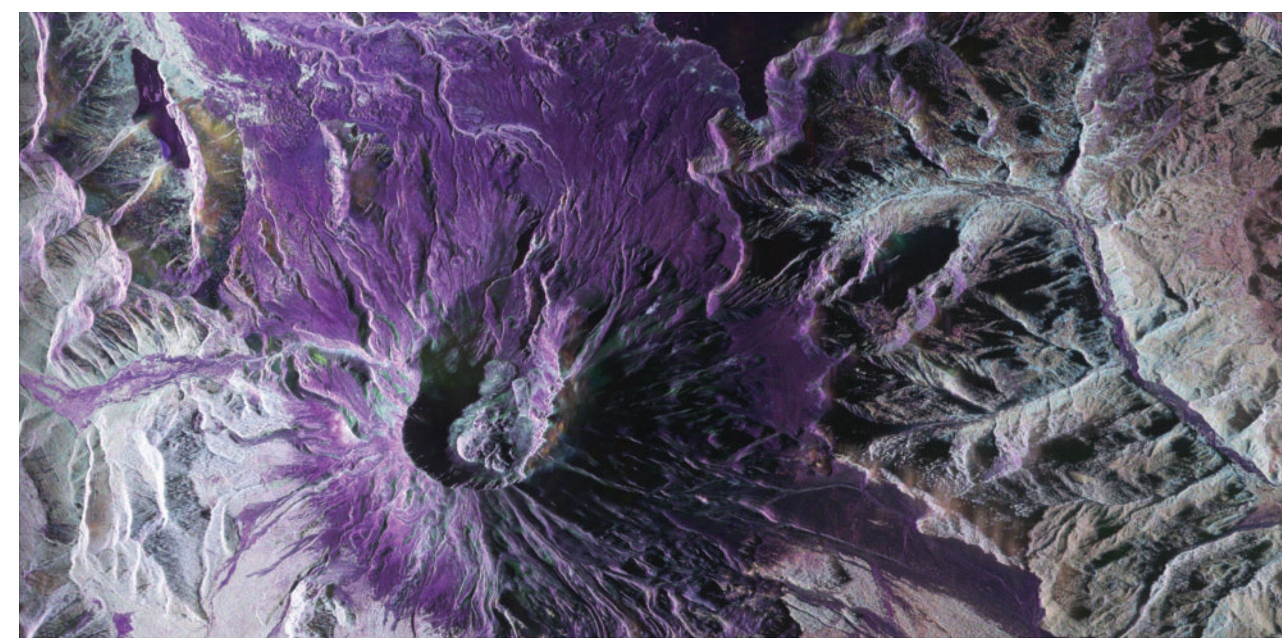
The IIP graduated one project in FY08: the Pathfinder Airborne Radar Ice Sounder (PARIS). This particular project completed 10 days of test flights over Greenland in 2007 that demonstrated the instrument's ability to measure the topography of bedrock under an ice sheet (basal topography) as well as ice sheet layering characteristics.

SPOTLIGHT: UAV-SAR Completes Over 25 Test Flights in FY08, Returns Science Data

The Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAV-SAR) project completed significant operational and test flights in FY08 on board the NASA Gulfstream III (G-III) aircraft. The flights, conducted over California and Washington, have clearly demonstrated the instrument's value as a science platform and have returned some stunning images.

UAV-SAR, a reconfigurable, polarimetric L-band SAR built at the Jet Propulsion Laboratory, is specifically designed to acquire airborne repeat pass SAR data for differential interferometric measurements. Repeat pass interferometry is a technique that requires the aircraft to fly each pass as close to the original flight line as possible. This feat is achieved using a sophisticated autopilot system developed at the NASA Dryden Flight Research Center that can repeat the flight path within a ten meter diameter tube.

Data collected by the UAV-SAR instrument on each repeat pass are compared to examine changes, to millimeter-level resolution, in the Earth's surface. The resulting surface displacement measurements are useful for a variety of scientific objectives, such as volcano and earthquake activity, ice velocity, hydrology, erosion, and even archeology. The project team is currently examining the modifications needed to mount the instrument pod on a Global Hawk UAV for missions requiring extended range or endurance.



This false color, composite image of Mt. St. Helens was constructed by assigning colors (red, blue, and green) to three of the polarimetric layers collected by a single pass of the UAV-SAR instrument from an altitude of 41,000 feet. The image shows an area approximately 20 kilometers wide with an original resolution of approximately 6 meters per pixel. Although covered with snow at the time, many features within the lava dome of Mount St. Helens are visible as the radar partially penetrates the snow layer. Also clearly visible is the tree line, in green, surrounding the peak.

2008 in Review: **Information Systems**

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 42 active investments in FY08, 10 of which graduated over the course of the year. All of the FY08 AIST program graduates advanced at least one TRL while active.

An AIST solicitation released in June 2008 is expected to award additional projects in early FY09. This solicitation focused on three areas that are critically needed to support future Earth science measurements:

- **Sensor System Support** to incorporate autonomy and rapid response in the sensing process and improve the science value of data;

- **Advanced Data Processing** to improve or enhance the information extracted from the data stream; and

- **Data Services Management** to better manage the growing body of Earth science data and allow for efficient exchange.

In June 2008, the 'Reconfigurable Sensor Networks for Fault-Tolerant In-Situ Sampling' project team deployed a fleet of three SnoMote robots to test their mobile sensor network on Mendenhall Glacier in Alaska. The autonomous SnoMotes are designed to gather in-situ science data in dangerous, volatile ice environments in order to augment remote sensing data with accurate ground-truth measurements. The tests demonstrated the sensor network, which allows the SnoMotes to self-deploy and efficiently reconfigure themselves based upon local conditions and detected areas of interest. Shown above are the Principal Investigator, Ayanna Howard (left), and team member Stephen Williams (right) with a SnoMote being readied for action. (Credit: Matt Heavner)

SPOTLIGHT: Progress Toward Sensor Webs

The idea of a 'Sensor Web' first surfaced within the NASA community in 1997 and the term has come to describe a network of sensors, or sensor pods, that have the ability to act as a whole and coordinate autonomously with each other and with the end user. The capability for synchronous effort by a disparate set of sensors will have a profound effect on future Earth science endeavors, exponentially increasing both the value of observations as well as the utility and lifespan of each sensor within a sensor web.

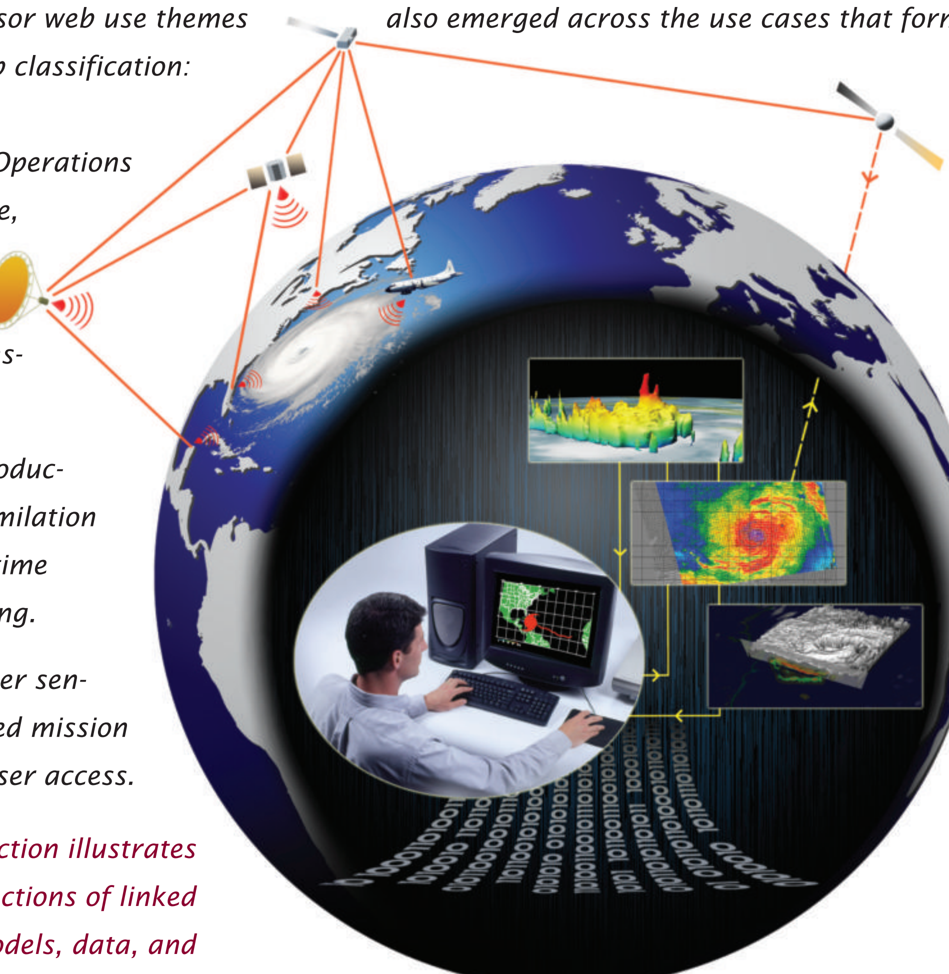
In 2006, the AIST program issued a targeted solicitation focused on the architecture and building blocks needed for future autonomous sensor webs. 28 projects were awarded funding and the AIST program has actively engaged these investigators through a series of workshops in order to achieve consensus on sensor web architectural principals as well as to spur collaborations.

Through these workshops a number of use case scenarios were developed – from atmospheric composition studies and forest fire identification to earthquake forecasting and water quality monitoring – that are directly applicable to nearly every NRC decadal survey measurement requirement. Three sensor web use themes also emerged across the use cases that form the basis for sensor web classification:

1) Autonomous Sensor Operations to enable rapid response, autonomous tasking, sensor management, and improved data transmission among sensors.

2) Autonomous Data Production for rapid data assimilation and ingestion and real-time forecasting and modelling.

3) User Support for better sensor scheduling, optimized mission design, and improved user access.



This artist's depiction illustrates the interactions of linked instruments, models, data, and users within a sensor web.

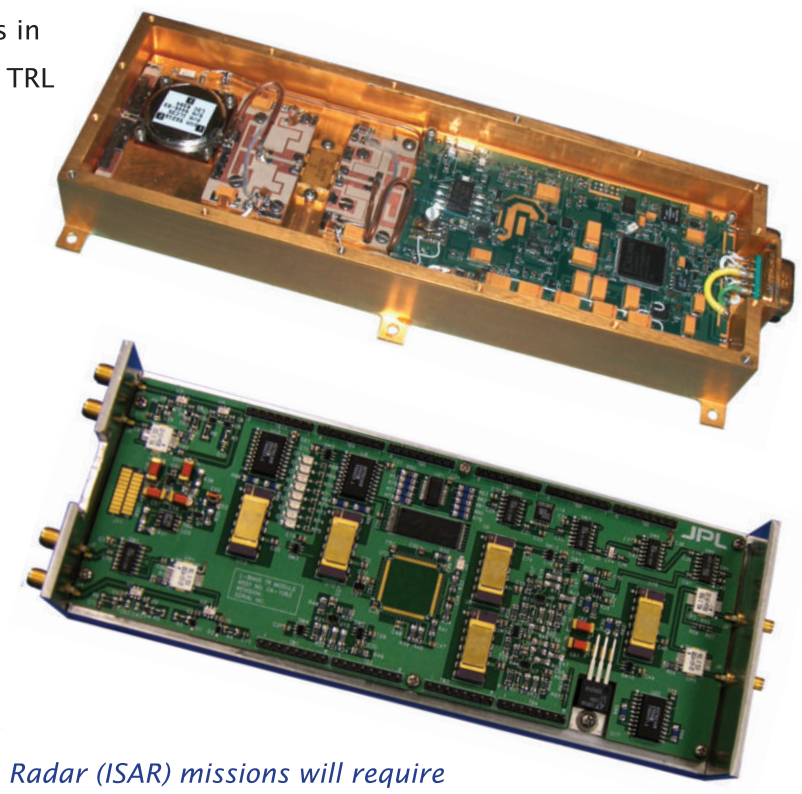
2008 in Review: **Components**

The Advanced Component Technology (ACT) program leads research, development, and testing of component- and subsystem-level technologies to advance the state-of-the-art of instruments, Earth- and space-based platforms, and information 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 FY08, the ACT program portfolio held 18 active investments. More projects will be added in FY09 through a competitive solicitation, released in May 2008, which highlighted four broad areas of interest for component technologies – active optical, passive optical, microwave, and calibration for radiation measurements. These areas have the potential for significant advancement in the technology readiness of the Earth science measurements recommended by the NRC decadal survey.

The ACT program graduated four projects in FY08, two of which advanced at least one TRL over their course of funding:

- Lightweight, Low Power, High Speed Digital Signal Distribution Technology for Thinned Aperture Radiometers
- Analog Radio-Frequency Interference Suppression System (ARFISS) for Microwave Radiometers
- Adaptive Self-Correcting Transmit / Receive module for Phase-Stable Array Antennas
- High-Power, Single-Frequency UV Laser Transmitter

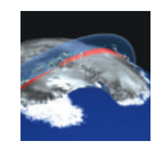


Future Interferometric Synthetic Aperture Radar (ISAR) missions will require large, lightweight, high power, phase-stable, electronically-steerable L-band phased-array antennas. A recently-completed, two-year ACT project at the Jet Propulsion Laboratory sought to develop a practical and low cost adaptive L-band Transmit / Receive (T/R) module, with an integrated calibrator, for use in ISAR antennas. Building upon T/R developments from a prior ACT task, the project team developed the first practical "smart T/R module" that provides stable output power at L-band and has ultra-stable phase and gain for interferometric ISAR applications. The project advanced two Technology Readiness Levels over the two years of funding. Above are two sides of the 30W module: the T/R module (top) and the control board (bottom).

2008 in Review: **Lasers**

The Laser Risk Reduction Program (LRRP) was established in 2001 by the NASA Administrator in response to recommendations by the Earth Science Independent Laser Review Panel. The LRRP has worked to formalize design, testing, and development procedures for durable laser/lidar systems and architectures, particularly in the critical One- and Two-micron wavelengths.

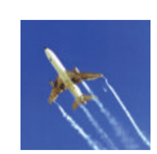
Laser/lidar remote sensing techniques satisfy a variety of measurement and operational requirements:



Earth Science: Clouds/ Aerosols, Tropospheric Winds, Ozone, Carbon Dioxide, Biomass, Water Vapor, Land, Ice, and Ocean, Surface Mapping, and Laser Altimetry

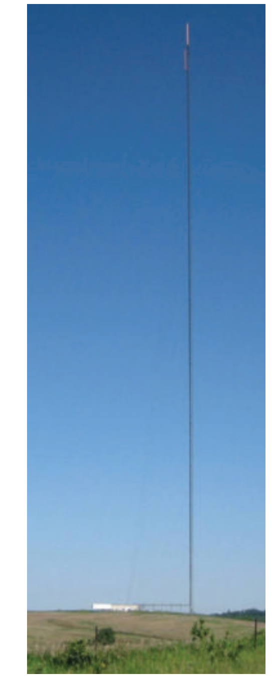
Space Science: Surface Materials, Physical State, Surface Topography, Molecular Species, and Atmospheric Composition / Dynamics

Exploration: Lander Guidance/Control, Atmospheric Winds, Biochemical Identification, Optical Communication, and Automated Rendezvous & Docking

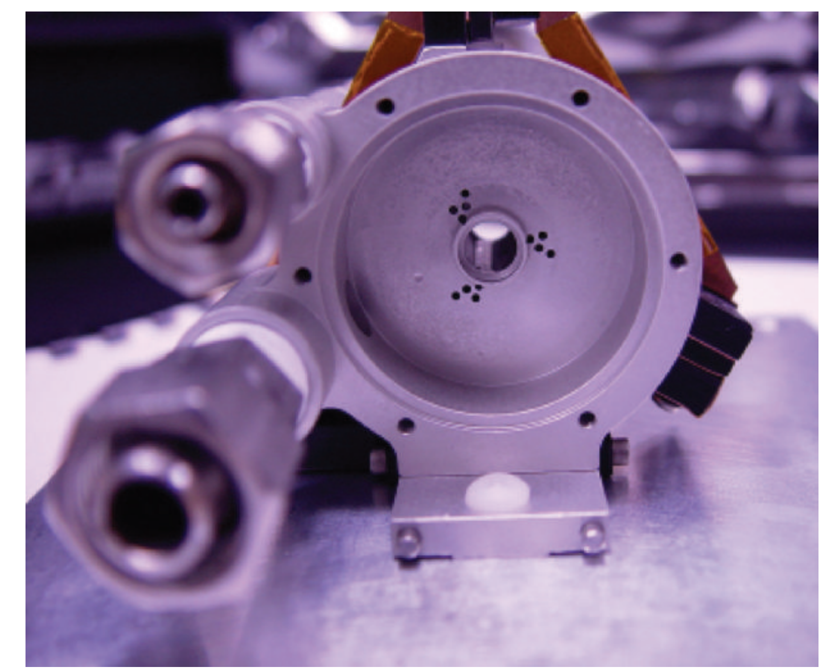


Aeronautics: Turbulence Detection, Wind Shear Detection, and Wake Vortices

In FY08, the LRRP funded several laser development projects at the NASA Langley Research Center.



An LRRP-funded seeded pulsed transmitter was integrated into a first-ever two micron direct detection DIAL measurement of Carbon Dioxide for a field experiment in West Branch, Iowa. At left, the 444.7 meter KWKB tower in West Branch provided an ideal platform for the instrument and the in-situ CO_2 measurements were timed to coincide with NOAA aircraft overflights. This work could eventually provide a full-time ground validation instrument for satellite CO_2 retrievals, such as those from NASA's Orbiting Carbon Observatory.



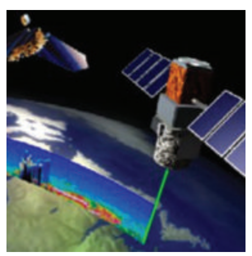
Supported by years of materials and diode advances, two-micron laser systems are now evolving to well engineered, ruggedized, and packaged transmitters. The component shown above is a five diode partially conductively cooled laser head with heritage from several LRRP projects. This laser head is now part of the transmitter for the IIP Doppler Aerosol Wind Lidar (DAWN) project (see page 10).

Future Challenges

The National Research Council decadal survey – "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond" – lays out a consensus vision and priorities for future Earth science endeavors and advises, among other strategies, that the cost risk of future missions be reduced by "investing early in the technological challenges."

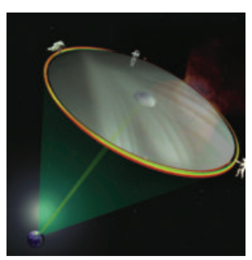
We recognize the importance of this statement. In fact, ESTO investments have, for several years, been buying down the risk of nearly all of the measurements recommended by the decadal survey. This is a testament to ESTO's best practices for technology development: competitive, peer-reviewed solicitations; active technology management; and broad-based, inclusive strategic planning. ESTO continues to monitor and match investments to the evolving needs of the Earth science community.

In addition to established technology goals, we have identified four areas that will serve a multitude of science disciplines:



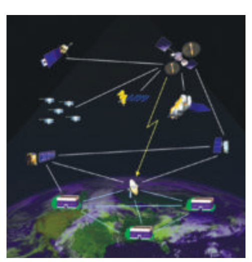
Active Remote Sensing Technologies to enable measurements of the atmosphere, hydrosphere, biosphere, and lithosphere.

- 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.

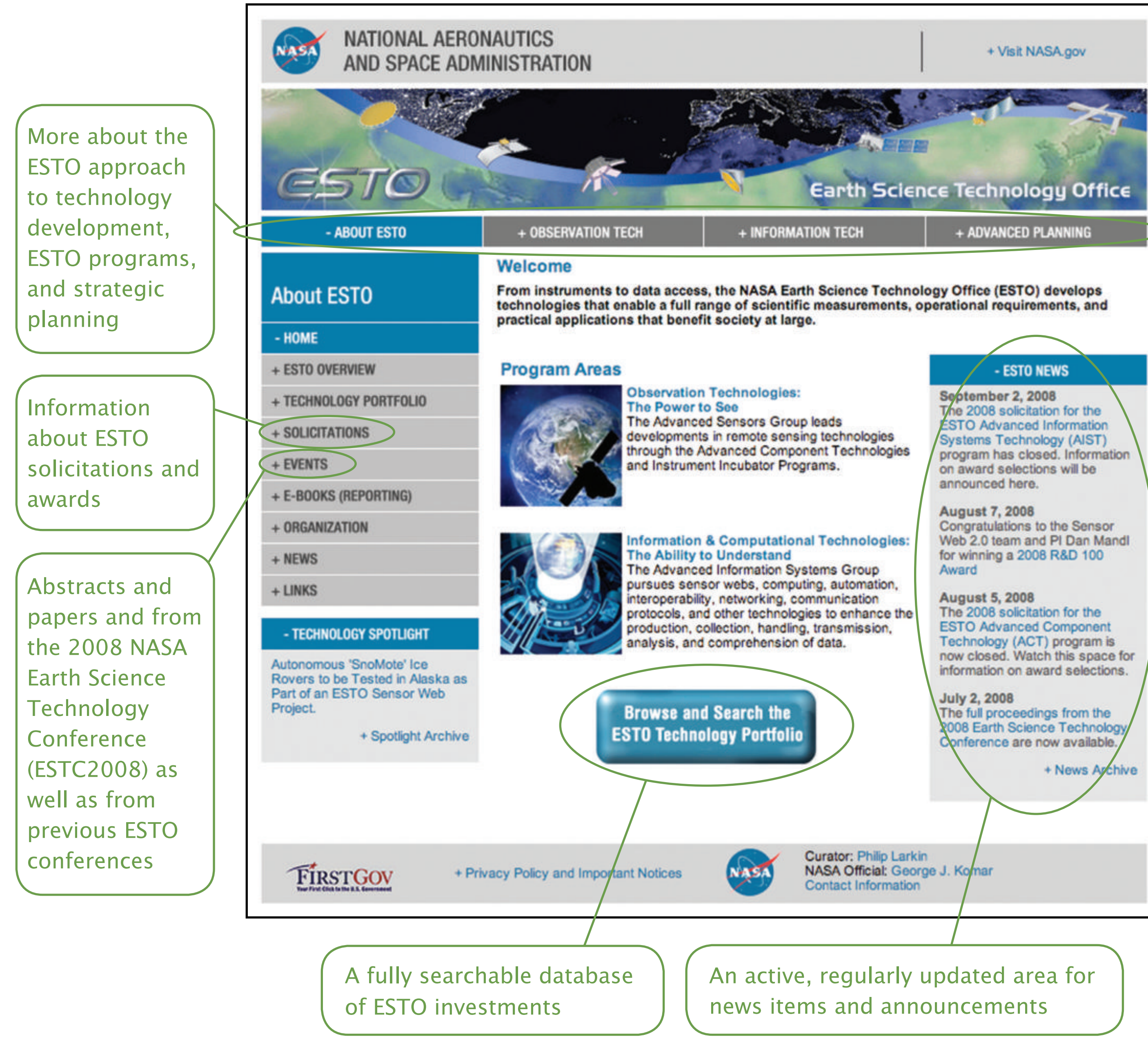
- Long-term weather prediction linking observations to numerical models
- Interconnected sensor webs that share information to enhance observations

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:



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