National Aeronautics and Space Administration

2016 Annual Report

NASA Earth Science Technology Office

Executive Summary

2016 was another full and productive year for technology development at the NASA Earth Science Technology Office (ESTO), with numerous successes in the selection of new projects and the advancement and infusion of technologies for science.

Of particular note, during the fiscal year ESTO selected six new projects through the first Sustainable Land Imaging-Technology (SLI-T) program solicitation, a new initiative to develop future Landsat-like instruments, sensors, components, and measurement concepts. More information on SLI-T can be found on page 5. *Additionally, 17 new projects were also added under the Instrument Incubator Program (IIP) in October 2017.*

ESTO continues to build upon a strong history of technology development and infusion. This year 34% of active ESTO technology projects advanced at least one Technology Readiness Level (TRL). Of the 733 completed projects in the ESTO portfolio, 33% have already been infused while an additional 46% have a path identified for future infusion in Earth observing missions or commercial applications. See pages 1-3 for more on ESTO programmatic metrics.

These successes demonstrate the hard work of our principal investigators and their collaborators. We welcome the new group of SLI-T and IIP investigators as they begin their selected projects. We look forward to their contributions that, along with existing projects, will ensure a bright future for Earth science.

George J. Komar
Program Director

Robert A. Bauer
Deputy Program Director

About ESTO

As the technology function within NASA's Earth Science Division, ESTO performs strategic technology planning and manages the development of a range of advanced technologies for future science measurements and operational requirements.

ESTO employs an open, flexible, science-driven strategy that relies on competition and peer review to produce the best, cutting-edge technologies for Earth science endeavors.

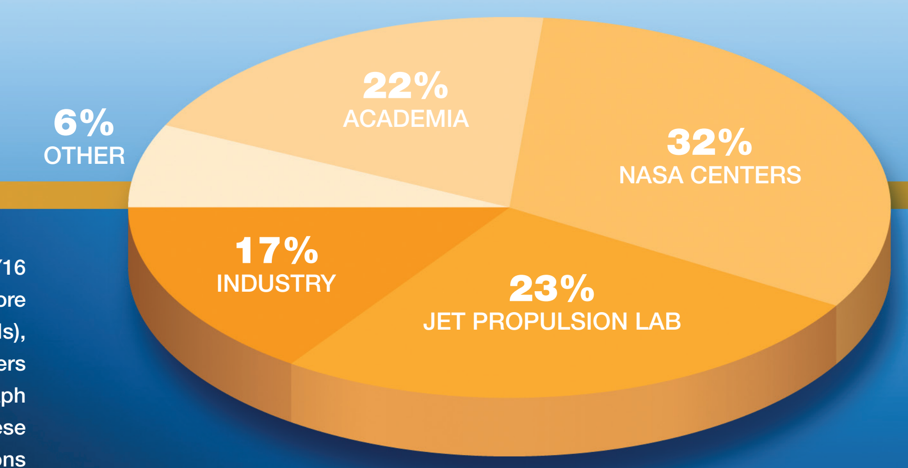
ESTO also applies a rigorous approach to technology development:

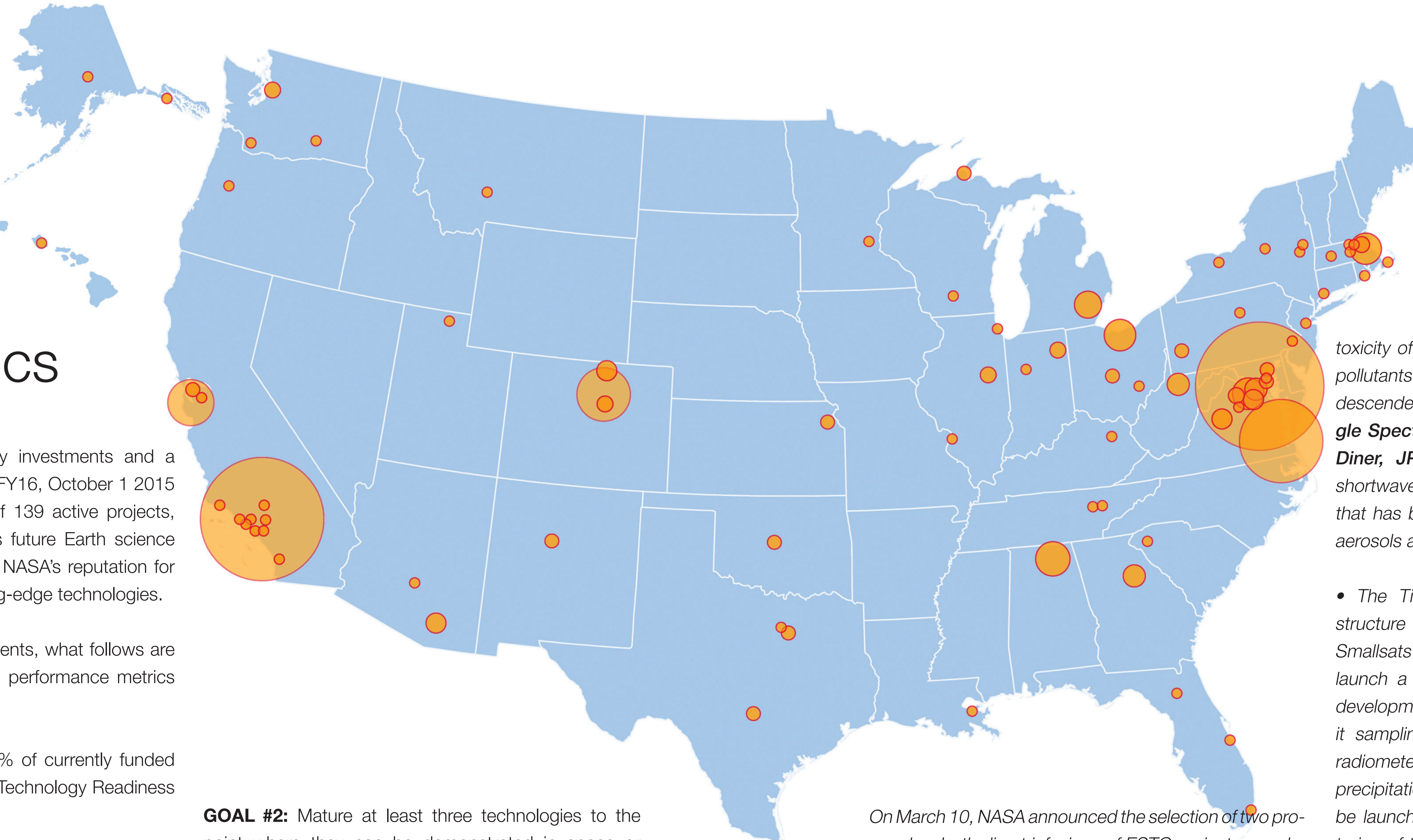
- Planning investments by careful analyses of science requirements
- Selecting and funding technologies through competitive solicitations and partnership opportunities
- Actively managing the progress of funded projects
- Facilitating the infusion of mature technologies into science measurements

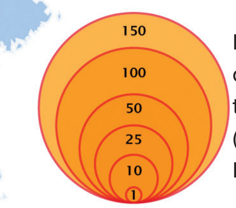
The results speak for themselves: a broad portfolio of well over 800 emerging technologies – 139 of which were active at some point during Fiscal Year 2016 (FY16) – ready to enable or enhance new science measurement capabilities as well as other infusion opportunities.

ESTO's technology portfolio enables end-to-end science measurements, from the instruments that make observations to the data systems and information products that make observations useful.

The 139 active projects during FY16 included the combined efforts of more than 560 principal investigators (PIs), co-investigators (Co-Is), and partners from a variety of institutions. The graph to the right gives the distribution of these participating institutions







Map provides geographical distribution of principal investigators for the 830 projects (active and completed) in the ESTO portfolio.

2016 Metrics

With 733 completed technology investments and a portfolio during fiscal year 2016 (FY16, October 1 2015 through September 30, 2016) of 139 active projects, ESTO drives innovation, enables future Earth science measurements, and strengthens NASA's reputation for developing and advancing leading-edge technologies.

To clarify ESTO's FY16 achievements, what follows are the year's results tied to NASA's performance metrics for ESTO:

GOAL #1: Annually advance 25% of currently funded technology projects at least one Technology Readiness Level (TRL).

FY16 RESULT: 34% of ESTO technology projects funded during FY16 advanced one or more TRL over the course of the fiscal year. 14 of these projects advanced more than one TRL. See the graph below for yearly comparisons. [Note: because of the periodicity of solicitations and reporting, interannual comparisons are not relevant.]

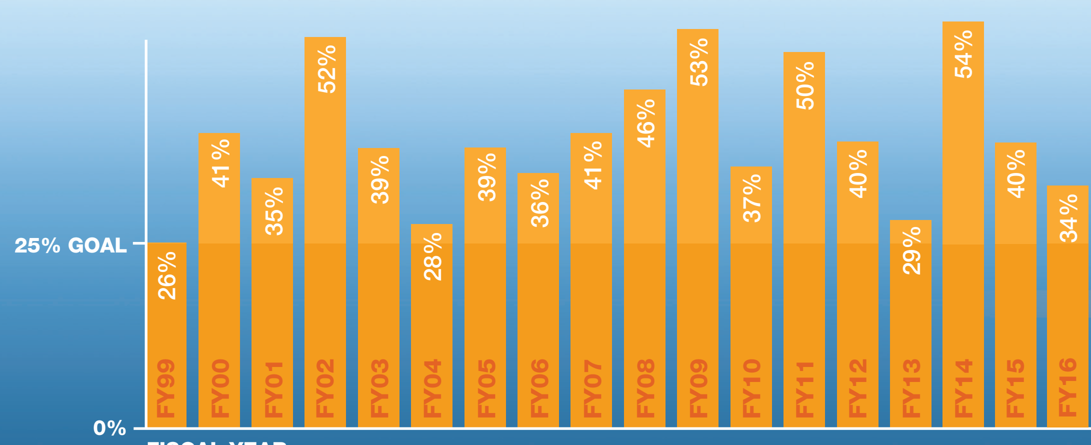
GOAL #2: Mature at least three technologies to the point where they can be demonstrated in space or in a relevant operational environment.

FY16 RESULT: At least 14 ESTO projects achieved infusion into science measurements, airborne campaigns, data systems, or follow-on development activities in FY16. Two notable examples follow.

On March 10, NASA announced the selection of two proposals – both direct infusions of ESTO projects – under the third solicitation of the Earth Venture Instrument (EV-I) program:

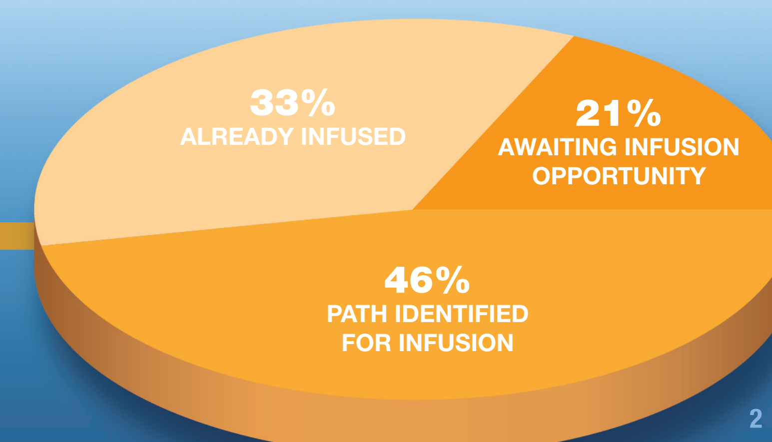
• The Multi-Angle Imager for Aerosols (MAIA) will make observations of small atmospheric aerosols which will be combined with health information to determine the toxicity of different particulate matter types in airborne pollutants over the world's major cities. MAIA is a direct descendent of the ESTO-funded ***Airborne Multi-angle Spectropolarimetric Imager (AirMSPI, PI: David Diner, JPL)****, an ultraviolet/visible and near-infrared/shortwave-infrared multi-angle polarimetric camera that has been flown repeatedly on aircraft to measure aerosols and clouds.*

• The Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) investigation will develop and launch a constellation of 12 CubeSats to study the development of tropical cyclones through rapid-revisit sampling. TROPICS will use scanning microwave radiometers to measure temperature, humidity, precipitation and cloud properties. The CubeSats will be launched into three orbital planes to enable monitoring of tropical cyclones with a revisit time of as little as 20 minutes. The TROPICS instrument will benefit from prior microwave receiver technology development as well as the ESTO-funded ***Microwave Radiometer Technology Acceleration (MiRaTA, PI: Kerri Cahoy, MIT)*** *project, a CubeSat under development to space-validate a new microwave radiometer.*



Percentage of Active Projects that Advanced at Least 1 TRL during each Fiscal Year.

ESTO's infusion success—drawn from the 733 completed projects through the end of FY16



2016 Metrics (continued)

GOAL #3: Enable a new science measurement or significantly improve the performance of an existing technique.

FY16 EXAMPLES:

DopplerScatt, a Ka-band Doppler scatterometer, conducted several validation flights onboard a Department of Energy B200 aircraft in mid-September, 2016, over coastal Oregon and Washington. The primary goal of the flights was to demonstrate the instrument's ability to take simultaneous measurements of ocean surface vector winds and currents, which would represent a new science capability.

Spatially and temporally coupled wind and current measurements could improve our understanding of air-sea interactions and their influence on heat transport, surface momentum, gas fluxes, ocean productivity, and marine biology.

The flights were also an opportunity to investigate the interaction between the Columbia River plume, fresh-water mixing and transport, and coastal ocean circulation.

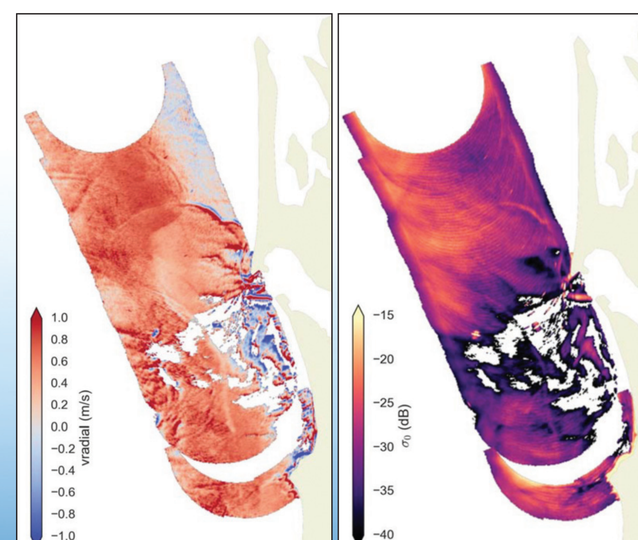
Although data processing from the flights continues, the demonstrations appear to have been successful. Ocean surface current velocity was mapped around the Columbia estuary and the radar backscatter was retrieved to be used for estimating surface winds.

While the airborne DopplerScatt lays the groundwork for an eventual spaceborne scatterometer, response from the science community has been positive. In 2017, the instrument may be used to support a coordinated effort to study the effects of the Mississippi River on ocean mixing, circulation, and sediment and nutrient transport.

Above: DopplerScatt hardware with some of the project team members

Below are preliminary results from the Columbia River estuary overflights at 200m resolution.
Left: Radial current velocity near the Columbia River estuary from a 09/13/16 flight, and corrected for aircraft motion.
Right: Radial surface current velocity corrected for aircraft motion near the Columbia River estuary from a 09/13/16 flight.

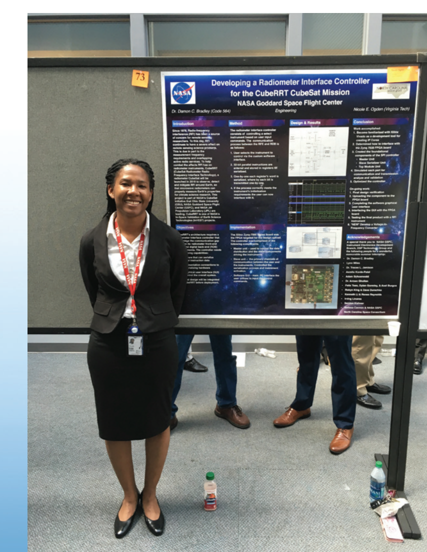
(Image credits: D. Perkovic-Martin and E. Rodriguez, JPL)



Student Participation

Student participation in ESTO projects has always been substantial. Since 1998, over 720 students from over 130 institutions have been involved in ESTO-funded work and at least 150 graduate-level degrees have been awarded. In FY2016 alone, 131 students – undergraduate, masters and doctorate – were actively involved with ESTO projects.

The MiRaTA (Microwave Radiometer Technology Acceleration) CubeSat project is made up of a broad team drawing from a national lab (MIT Lincoln Laboratory), universities (including MIT and University of Massachusetts), NASA, and NOAA. Students involved in the projects bring boundless energy that can be effectively brought to bear under the guidance of seasoned experts and faculty. (Credit: MIT)



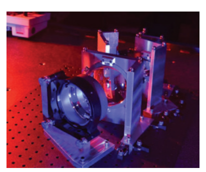
During an internship at NASA Goddard Space Flight Center, Nicole Ogden, a PhD student at Virginia Tech, worked on the radiometer interface controller for the CubeRRT CubeSat project. CubeRRT (CubeSat Radiometer Radio Frequency Interface Technology) is a small satellite under development to demonstrate wideband RFI mitigating backend technologies vital for future space-borne microwave radiometers. (Credit: Larkin/NASA)

New Tech Initiatives

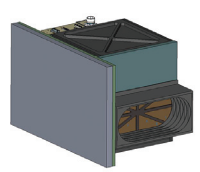
Sustainable Land Imaging-Technology (SLI-T)

Since 1972, the Landsat series of satellites have provided multispectral measurements of land and coastal regions, the longest continuous record of Earth's land areas from space. While Landsat data provide consistent and reliable information for scientific research, policy, and commercial uses, there has not been a robust plan to assure Landsat-like measurements in future decades. A 2013 report from the National Research Council (Landsat and Beyond: Sustaining and Enhancing the Nation's Land Imaging Program) detailed a number of recommendations for sustainable land imaging, and a 2015 Presidential budget request for FY16 echoed the recommendations, including the investment in land-imaging technologies. In response, NASA initiated the Sustainable Land Imaging – Technology (SLI-T) program to support innovative technology development activities leading to new Landsat-like instruments, sensors, components, and measurement concepts.

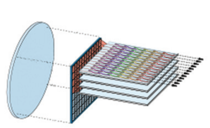
The SLI-T program issued its first competitive solicitation in December 2015 and awarded six projects, out of 33 proposals received, in August 2016. The solicitation sought proposals in two categories: 1) Advanced Technology Demonstrations (ATD) that provide improved, innovative, full-instrument concepts for potential infusion into the architecture and design of Landsat-10; and 2) Technology Investments (TI) to develop and mature component or breadboard-level technologies that have long-term potential to significantly improve future land imaging instruments. These new projects are as follows:



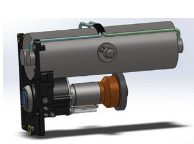
Compact Hyperspectral Prism Spectrometer (CHPS)
PI: Thomas Kampe, Ball Aerospace & Technologies Corporation - CHIPS is a new visible-to-shortwave (VSWIR) prism imaging spectrometer design that offers a path to enhanced science while maintaining continuity with legacy Landsat multispectral measurements. CHPS avoids the straylight shortcomings of other imaging spectrometer forms and accommodates full aperture, full optical path calibration to ensure high radiometric accuracy.



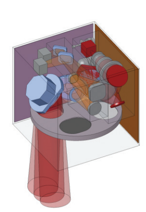
Advanced Technology Land Imaging Spectroradiometer (ATLIS)
PI: Jeffery Puschell, Raytheon Corporation - ATLIS is a small multispectral pushbroom imager designed to provide visible through shortwave (VSWIR) calibrated imagery in a an package that has 160x less volume and 16x less mass than the Landsat-8 Operational Land Imager. The project team is building and testing a single spectral band prototype ATLIS to demonstrate the wide field of view, fast optics, small detector approach.



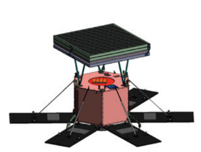
Sustainable Land Imaging Technology: Integrated Photonic Imaging Spectrometer
PI: Stephanie Sandor-Leahy, Northrup Grumman Systems Corporation - This project is building and testing a next-generation, heterogeneously integrated photonic instrument covering two SLI bands – band 9 (1.36 – 1.39 μm) and band 6 (1.56 – 1.66 μm). The use of lithographically patterned photonic waveguide technology could mean significant instrument mass and volume reduction, 7x and 25x respectively, compared to the current multispectral instrument approach.



Long Wavelength Infrared Focal Plane Array for Land Imaging
PI: David Ting, Jet Propulsion Laboratory (JPL) - This project is utilizing the JPL-developed high operating temperature barrier infrared detector (HOT-BIRD), which has proven performance in mid-wavelength infrared, in a Landsat-8 focal plane array (FPA) format. The detector could enable higher operating temperatures, thus reducing the cooling requirements and potentially prolonging instrument lifetime. The team is also performing characterization of the FPA.



Reduced Envelope Multi-Spectral Imager (REMI)
PI: Paula Wamsley, Ball Aerospace & Technologies Corporation - REMI is a compact multispectral instrument that meets heritage Landsat requirements – Visible through Thermal IR – in a single payload. Rather than the previous whisk or push broom scan architectures, REMI's step-stare scan architecture could lower size, weight, and power requirements through reduced aperture, combined apertures of visible through thermal IR, and an improved calibration source.



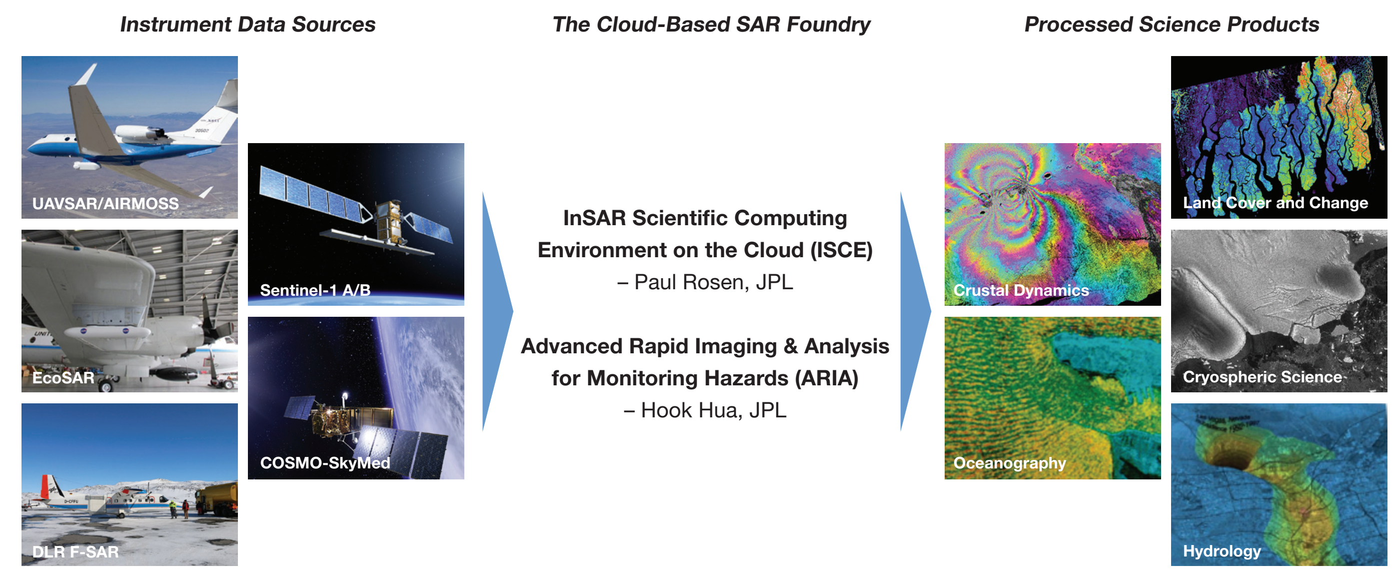
Multi-Spectral, Low-Mass, High-Resolution Integrated Photonic Land Imaging Technology
PI: Ben Yoo, University of California, Davis - This imaging sensor concept provides a low mass, low-volume alternative to the traditional bulky optical telescope and focal plane detector array. The design features micron scale optical waveguides and nanophotonic structures to form the interferometers.

ATD TI

SAR Science Data Foundry

Synthetic Aperture Radar (SAR) instruments are useful for a variety of science measurements, from surface deformation for monitoring earthquakes, volcanos, and subsidence to characterizing biomass. But the processing of SAR data can be cumbersome; SAR data is often processed "by hand," using highly-specialized, slow, and labor-intensive processes. Today, growing volumes of SAR Instrument data remain unprocessed to higher level science products (as much as 500 terabytes and growing by about two terrabytes each day).

Two Advanced Information Systems Technology (AIST) projects have joined forces to create a new cloud-based SAR instrument support system: the SAR Science Data Processing (SDP) Foundry. The new integrated system will accept Level-0 and Level-1 SAR data and produce quality tags, metadata and data products defined and approved by science teams. Processing upgrades will be leveraged across instruments and disciplines, and pay-as-you-go cloud processing allows investigators to select and quickly produce science products for use in science and disaster response.



A Managed Cloud Environment

In 2016, ESTO launched a cloud computing environment to facilitate information systems research for Earth science. Managed by the Advanced Information Systems Technology (AIST) program, the AIST Managed Cloud Environment (AMCE) is a shared computer processing resource that fully conforms to NASA security and information technology standards. The AMCE platform allows investigators to conduct project research using NASA infusion standards from the beginning, in a more cost-effective manner, and without concern for layering additional security compliance, potentially speeding successful adoption by end users and NASA applications. The common platform could also spur collaborations and aid in application testing.

The AMCE went live in July 2016 and five existing AIST projects have been on-ramped. An additional 10 projects are slated to move to the AMCE in 2017.

2016 in Review: Instruments

The Instrument Incubator Program (IIP) provides funding for new instrument and observation techniques, from concept to breadboard and flight demonstrations. Instrument technology development of this scale, outside of a flight project, consistently leads to smaller, less resource-intensive instruments that reduce the costs and risks of mission instrumentation.

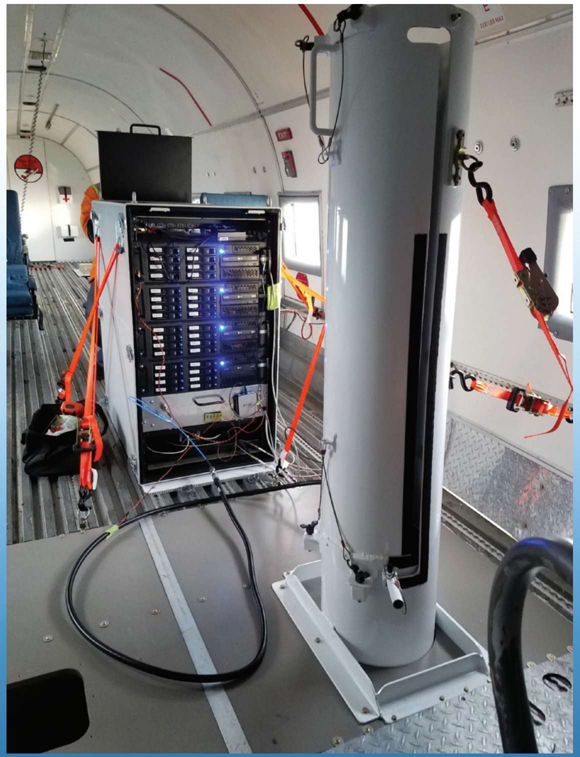
The IIP included 23 active projects in FY16. Another 17 were added in October 2017 through a competitive solicitation. These new awards are as follows:

- *A Solar Occultation Instrument Suitable for Constellations of Small Satellites* - Scott Bailey, Virginia Tech
- *Stratospheric Aerosol and Gas Experiment (SAGE) IV Pathfinder* - Robert Damadeo, Langley Research Center
- *Wideband Autocorrelation Radiometer Receiver Development and Demonstration for Direct Measurement of Terrestrial Snow and Ice Accumulation* - Roger De Roo, University of Michigan
- *Advanced Development of a Multi-Angle Stratospheric Aerosol Radiometer (MASTAR)* - Matthew DeLand, Science Systems and Applications, Inc.
- *Multi-Band Radiometric Imager Utilizing Uncooled Microbolometer Arrays with Piezo Backscan for Earth Observation Mission Applications* - Philip Ely, DRS Technologies
- *Compact Midwave Imaging System* - Michael Kelly, Johns Hopkins University Applied Physics Lab
- *Development and Demonstration of an Airborne Differential Absorption Radar for Humidity Sounding Inside Clouds* - Matthew Lebsock, Jet Propulsion Laboratory (JPL)
- *Stratospheric Water Inventory, Tomography of Convective Hydration (SWITCH)* - Nathaniel Livesey, JPL
- *Chrisp Compact VNIR/SWIR Imaging Spectrometer* - Ronald Lockwood, MIT Lincoln Laboratory
- *CARBO: The Carbon Balance Observatory* - Charles Miller, JPL
- *An Instrument Concept for Combined Observations of GNSS and Astronomical Sources Through a Standard Signal Path for Geodetic Applications* - David Munton, University of Texas, Austin
- *Miniaturized Imaging Spectrometer to Measure Vegetation Structure and Function: MiniSpec* - Jon Ranson, Goddard Space Flight Center
- *Next Generation GNSS Bistatic Radar Receiver* - Chris Ruf, University of Michigan
- *Multi Application Smallsat Tri-Band Radar* - Mauricio Sanchez-Barbetty, JPL
- *Tunable Light-Guide Image Processing Snapshot Spectrometer (TuLIPSS) for Earth Science Research and Observation* - Tomasz Tkaczyk, Rice University
- *SWIRP: Compact Submm-Wave and LWIR Polarimeters for Cirrus Ice Properties* - Dong Wu, Goddard Space Flight Center
- *SRI CubeSat Imaging Radar for Earth Science: Instrument Development and Demonstration (CIRES-IDD)* - Lauren Wye, SRI International

Three projects graduated from IIP funding in FY16, all of which advanced at least one Technology Readiness Level:

- *Risk reduction for the PATH mission* - Bjorn Lambrigtsen, JPL
- *Aircraft deployable UV-SWIR multiangle spectropolarimetric imager (AirMSPI-2)* - David Diner, JPL
- *A deployable 4-meter 180 to 680 GHz antenna for the* Scanning Microwave Limb Sounder (SMLS) - Richard Cofield, JPL

Below: The UWBRAD instrument installed in the DC-3T aircraft. The cylinder in the foreground is the deployable “periscope” antenna, and the instrument electronics are housed in the rack in the background.
Facing page: A view of the Canadian Rockies near the Columbia Icefield during the 9/5/2016 flight test.
(Image Credits: Joel Johnson/Ohio State University)



SPOTLIGHT:

First Ground and Airborne Demonstrations of a New Method for Ice Sheet Subsurface Temperature Measurements

Physical temperature plays an important role in influencing stress-strain relationships in the ice sheet volume, and therefore impacts ice sheet dynamics including deformation and flow across the ice sheet base. Previous studies and models have shown the potential of multi-frequency brightness temperature measurements to obtain deep ice sheet temperature information, given assumed ice sheet internal temperatures, electromagnetic permittivity, and other physical parameters such as density and particle grain size.

A new instrument, the Ultra-wideband Software-Defined Microwave Radiometer (UWBRAD), aims to provide measurements of ice sheet thermal emission in order to remotely sense internal ice sheet temperature information. UWBRAD is designed to provide brightness temperature observations over the 0.5-2 GHz range using multiple frequency channels and full-bandwidth sampling of each channel. No methods currently exist for remotely sensing ice sheet internal temperatures; presently the only measured information is obtained from a small number of deep ice core sites. As an airborne instrument, UWBRAD could obtain data over wide areas.

In November 2015, a four-channel prototype of the UWBRAD (540, 900, 1380, and 1740 MHz) was successfully demonstrated on a tower at the Dome-C site in Antarctica. The lower frequencies penetrated several kilometers within the ice and showed warmer temperatures with increasing depth. In 2016, the UWBRAD team applied lessons learned from the prototype demonstration to a full 12-channel airborne instrument, which had its first test flights in September onboard a Kenn Borek Airlines DC-3T aircraft over Greenland and parts of Canada. The tests provided ~ 10 hours of the first ultra-wideband microwave radiometer measurements of geophysical scenes including ice sheets. The project team intends to conduct additional flights and collect science data in early 2017.

2016 in Review: Information Systems

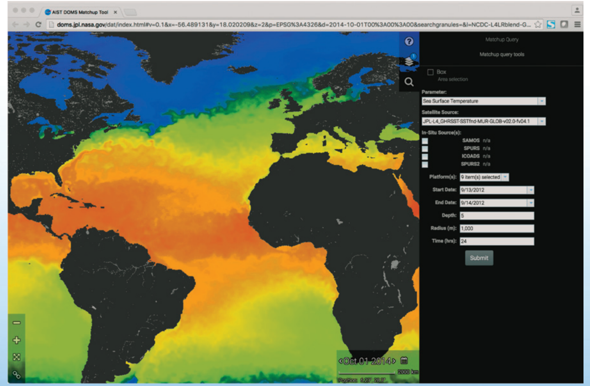
Advanced information systems play a critical role in the collection, handling, and management of large amounts of Earth science data, both in space and on the ground. Advanced computing and transmission concepts that permit the dissemination and management of terabytes of data are essential to NASA's vision of a 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.

16 AIST projects completed this year, 10 of which advanced at least two TRLs over their course of funding. These FY16 graduates are as follows:

- *Automated Event Service (AES): Efficient and Flexible Searching for Earth Science Phenomena* – Thomas Clune, Goddard Space Flight Center (GSFC)
- *A mission simulation and evaluation platform for terrestrial hydrology using the NASA Land Information System (LIS)* – Christa Peters-Lidard, GSFC
- *Multivariate Data Fusion and Uncertainty Quantification for Remote Sensing* – Amy Braverman, Jet Propulsion Laboratory (JPL)
- *Unified Simulator for Earth Remote Sensing (USERS)* – Simone Tanelli, JPL
- *ISCE: InSAR Scientific Computing Environment on the Cloud* – Paul Rosen, JPL
- *Fusion of Hurricane Models and Observations: Developing the Technology to Improve the Forecasts* – Svetla Hristova-Veleva, JPL
- *Advanced Rapid Imaging & Analysis for Monitoring Hazards (ARIA-MH)* – Hook Hua, JPL
- *Next-Generation Real-Time Geodetic Station Sensor Web for Natural Hazards Research and Applications* – Yehuda Bock, University of San Diego/Scripps
- *An Advanced Learning Framework for High Dimensional Multi-Sensor Remote Sensing Data* – Melba Crawford, Purdue University
- *PROBE: An Interactive Environment to Enhance Model Development Using Process-Based Diagnostics* – Thomas Clune, GSFC
- *Demonstration of AIST Cloud Computing Environment* – Chaowei (Phil) Yang, George Mason University
- *Demonstration of Oculus Virtual Reality Technology Phase 1* – Daniel Duffy, GSFC

Online Tool for Oceanographic Data Unveiled

The Distributed Oceanographic Match-up Service (DOMS) is a web-accessible service tool that will reconcile satellite and in situ datasets. When fully implemented online, DOMS will provide a mechanism for users to input a series of geospatial references for satellite observations (e.g., location, date, and time) and receive the in situ observations that are "matched" to the satellite data within selectable time and space tolerances of the satellite observations. The inverse – inputting in situ geospatial data (e.g., positions of moorings, floats, or ships) and returning corresponding satellite observations will also be supported. The DOMS prototype already includes several datasets and will also be readily extendable to other in situ and satellite collections to support additional science disciplines. Visit DOMS online to learn more: https://mdc.coaps.fsu.edu/doms



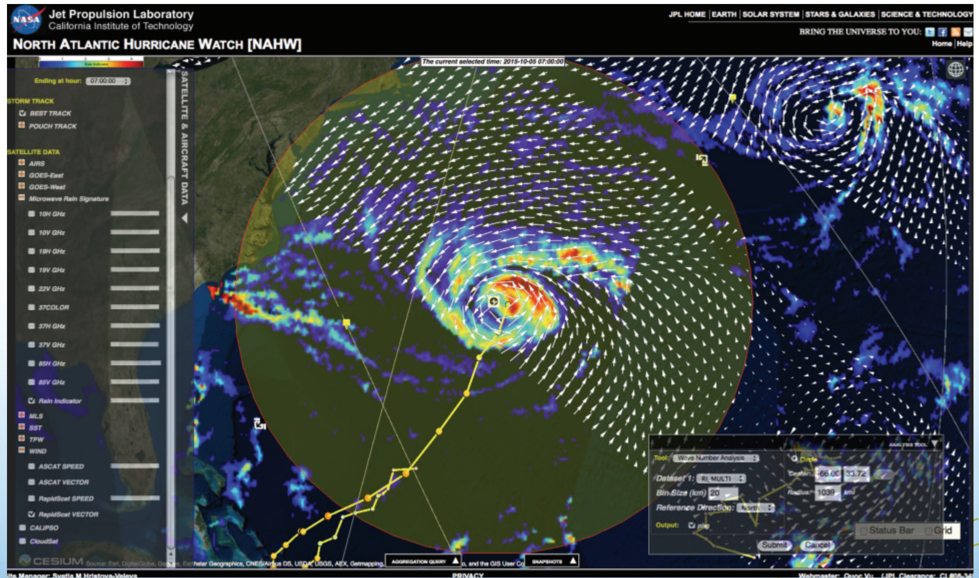
- *Constant Modulation Transfer Function (MTF) Interpolator Study* – Richard Quinn, Lockheed Martin Space Systems
- *Earth Science Big Data Architecture* – Daniel Crichton, JPL
- *Alternative Data Models to Improve Data Access* – Ted Habermann, The HDF Group
- *A Framework for Comparing Data Containers* – Kamalika Das, University of California Santa Cruz: UARC at ARC

An AIST program solicitation was released in early FY17 as element A.41 of the 2016 NASA ROSES omnibus announcement. Notices of Intent were requested by December 21 and proposals were due February 16, 2017. Awards are anticipated by mid-2017.

SPOTLIGHT:

Tropical Cyclone Information System (TCIS) Demonstrated for Hurricane Joaquin

In October 2015, products from the AIST-funded TCIS were presented to NOAA's National Hurricane Center and the Hurricane Research Division (HRD) for use in analyzing Hurricane Joaquin. TCIS provides scientists the ability to overlay user-selected observational data on top of a variety of user-selected model predictions to perform online analysis on models and observations to improve forecasts. The output from a TCIS online analysis tool, developed in collaboration with HRD, suggested the potential for Joaquin's rapid intensification several hours before it actually happened. Moving forward, TCIS analyses could be used to provide valuable new information for understanding and forecasting hurricanes, particularly rapid intensification processes.



Recent enhancements to TCIS support interactive region selection, model and data acquisition, statistical comparison, and visualization and analysis. The image above reveals the structure of Hurricane Joaquin as depicted by near-coincident observations of the surface wind (from RapidScat) and rain fields (from passive microwave observations). (Credit: S. Hirstova-Veleva JPL)

2016 in Review: Components

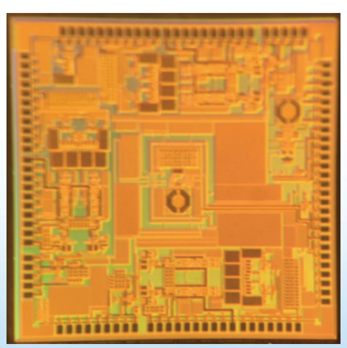
The Advanced Component Technology (ACT) program leads research, development, testing, and demonstration of component- and subsystem-level technologies for use in state-of-the-art Earth science instruments and information systems. The ACT program funding is primarily geared toward producing technologies that reduce the risk, cost, size, mass, and development time of future space-borne and airborne missions.

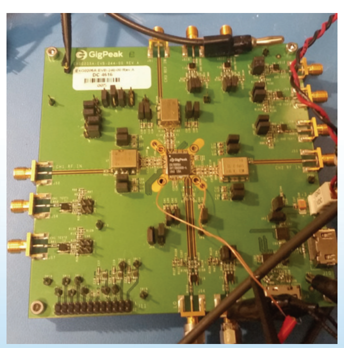
The ACT program aims to mature component technologies to a level that allows further development by other NASA programs or their integration into other technology projects, such as those selected by the Instrument Incubator Program. In other cases, the ACT program produces component technologies of sufficient readiness that they can be directly infused into mission development or science campaign activities.

In FY16, the ACT program portfolio held 17 investments, seven of which completed during the fiscal year:

- *Development of Immersion Gratings to Enable a Compact Architecture for High Spectral and Spatial Resolution Imaging* - Daniel Jaffe, University of Texas at Austin
- *Demonstration of a Hyperspectral Microwave Receiver Subsystem* - William Blackwell, MIT Lincoln Laboratory
- *A 2-micron Pulsed Laser Transmitter for Direct Detection Column CO2 Measurement from Space* - Jirong Yu, Langley Research Center
- *Design and Fabrication of a Breadboard, Fully Conductively Cooled, 2-Micron, Pulsed Laser for the 3-D Winds Decadal Survey Mission* - Upendra Singh, Langley Research Center
- *Advanced W-Band Gallium Nitride Monolithic Microwave Integrated Circuits (MMICs) for Doppler Cloud Radar Supporting ACE* - King Man Andy Fung, Jet Propulsion Laboratory
- *Fabry-Perot for the Integrated Direct Detection Lidar (FIDDL)* - Sara Tucker, Ball Aerospace & Technologies Corp
- *SRI CubeSat Imaging Radar for Earth Science (SRI-CIRES)* - Lauren Wye, SRI International

Six of these completed ACT projects advanced at least one TRL during their course of funding. The next ACT solicitation is anticipated in 2017.





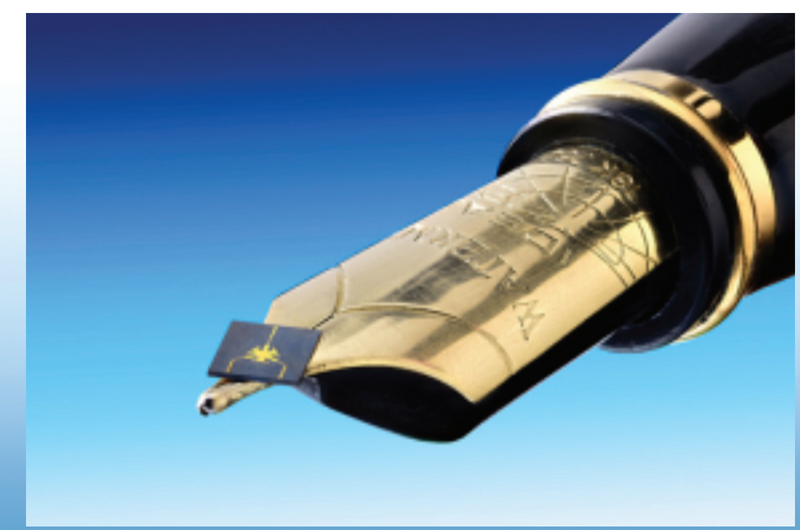
A 2013 Advanced Component Technology project at GigOptix Inc (PI: Michael Shaw) wrapped up design and fabrication work this year on a new ASIC (Application Specific Integrated Circuit). Intended for high-quality radio occultation (RO) weather observations using Global Navigations System Satellite (GNSS) signals, the ASICs would be easier to accommodate on missions of opportunity and could enable constellations of small satellites that could increase weather prediction ability. The design supports four radio frequency (RF) inputs capable of receiving three GNSS signals per input in a single ASIC. Multiple RF channels on a GNSS receiver is a unique feature which could enable precision beam forming; large beam forming arrays may provide the necessary signal to noise ratio to produce ocean altimetry and scatterometry observations. Current designs use four Radio Frequency Data Communications (RFDC) chips per antenna and can consume roughly 10W of power; the new ASIC uses only about 1W and is more than ten times smaller in size. In 2017, the project team will integrate the ASIC into a GNSS receiver at the Jet Propulsion Laboratory for further testing and perform temperature qualification. Shown above are the fabricated chip **(left)** and a test board **(right)**. (Images credit: M. Shaw/GigOptix)

SPOTLIGHT:

Progress Toward Ultra-lightweight, Compact, Magnetless Circulators

An ACT project at Metamagnetics Inc. (PI: Anton Geiler) is developing ultra-lightweight, compact, high-performance, magnetless circulators for use in sensors and communications phased arrays. A circulator provides duplex capability in a phased array transmit/receive (T/R) module and isolates amplifiers from unwanted reflections. Conventional T/R modules use ferrite circulators, which occupy a large volume because of the permanent magnet required to provide the necessary magnetic bias field. This effort is developing a circulator substrate that does not require external biasing and which would allow a 90% reduction in volume and weight. The circulator design is also promising because of the potential for exceptional shock, vibration, and radiation tolerance. The project team finalized a 3rd prototype of the circulator in 2016 and will begin subsystem integration, testing, and environmental testing in 2017.

Although targeted for the cloud radar proposed by the 2007 National Research Council Decadal Survey for Earth Science for NASA for the Aerosol/Cloud/Ecosystems (ACE) mission concept, this technology has potential application for many space missions, for science as well as communications. The project team is also working closely with the Wide-Swath Shared Aperture Cloud Radar (WiSCR) team, an Instrument Incubator Program project, to infuse the new circulators.



Left: One of the new circulators, on the tip of a fountain pen nib for scale, and **above:** next to a traditional ferrite circulator (note the protruding cylindrical magnet).
(Images credit: Metamagnetics)

2016 in Review: Space Validation

NASA has an ambitious vision for future Earth observations, with emerging technologies paving the way toward new Earth science measurements. Promising new capabilities, however, bring complexity and risk. While ground and airborne testing of new technologies is common practice, the need for validation in the hazardous environment of space is critical and ongoing. Once validated in space, technologies are generally more adoptable, even beyond the intended mission.

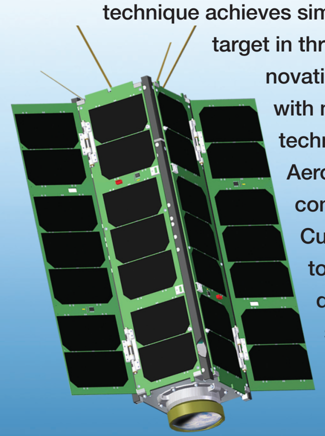
The In-Space Validation of Earth Science Technologies (InVEST) program facilitates the space demonstration of key technology projects. Nine projects have been awarded through InVEST program solicitations – five in 2012 and four in 2015 – all of which utilize a CubeSat platform.*

The first of the 2012 set of InVEST projects launched in 2016 (See RAVAN on page 14), and three others are preparing for launch in 2017:

HARP

J. Vanderlei Martins, University of Maryland Baltimore County
Launch: August 2017

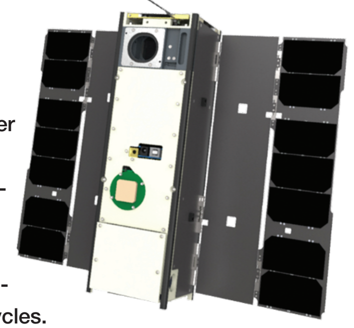
The HARP project seeks to demonstrate the capabilities of a highly accurate wide feld-of-view hyper-angular imaging polarimeter for characterizing aerosol and cloud properties. The HARP instrument splits three spatially identical images into three independent polarizers and detector arrays. This technique achieves simultaneous imagery of the same ground target in three polarization states and is the key innovation to achieve high polarimetric accuracy with no moving parts. Once demonstrated, the technology could be applicable to the NASA Aerosol-Cloud-Ecosystem (ACE) mission concept. The spacecraft will consist of a 3U CubeSat with 3-axis stabilization designed to keep the image optics pointing nadir during data collection but maximizing solar panel sun pointing otherwise. The hyper-angular capability is achieved by acquiring overlapping images at very fast speeds. (Image credit: J. V.. Martins)

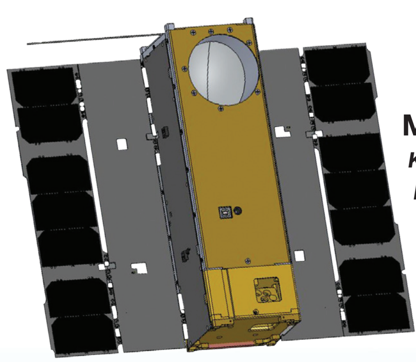


IceCube

Dong Wu, NASA Goddard Space Flight Center
Launch: March 2017

IceCube will space-qualify and demonstrate an 883-gigahertz submillimeter-wave receiver that could eventually lead to a radiometer instrument capable of accurate, global measurements of atmospheric ice. A daily assessment of the global distribution of atmospheric ice will help describe the linkage between the hydrologic and energy cycles. Ice clouds affect Earth's emission of infrared energy into space and the reflection and absorption of solar energy. While submillimeter receivers have flown previously in airborne missions, this demonstration will raise its technology-readiness level for eventual deployment on a satellite, such as on the Aerosol-Cloud-Ecosystems (ACE) mission concept. (Image credit: D. Wu)





MiRaTA

Kerri Cahoy, MIT
Launch: September 2017

Microwave radiometer measurements and GPS radio occultation (GPSRO) measurements of all-weather temperature and humidity provide key contributions toward improved weather forecasting. The Microwave Radiometer Technology Acceleration (MiRaTA) is a 3-unit (3U) CubeSat that will validate multiple technologies in both passive microwave radiometry and GPS radio occultation, including a space demonstration of new miniature microwave radiometers operating near 52-58, 175-191, and 206-208 GHz. On orbit, MiRaTA will execute periodic pitch-up maneuvers so that the radiometer and GPSRO observations sound overlapping volumes of atmosphere through the Earth's limb. To validate system performance, observations will be compared to radiosondes, global high-resolution analysis fields, and other satellite observations. MiRaTA will demonstrate, for the first time, how GPSRO can be used as a radiometer in-space calibration source to validate atmospheric soundings on orbit in real-time. (Image credit: K. Cahoy)

* A CUBESAT PRIMER

Normally launched as a secondary payload to a larger mission, a CubeSat is a type of nanosatellite often used for scientific research or technology validation. A basic 1 unit (1U) CubeSat measures 11x10x10 cm with a mass of up to 1.33 kg. Multiple units can be combined to form 2U, 3U, and even 6U configurations. The CubeSat standard was created by California Polytechnic State University and Stanford University following the first launch of 6 CubeSats in 2003.

SPOTLIGHT:

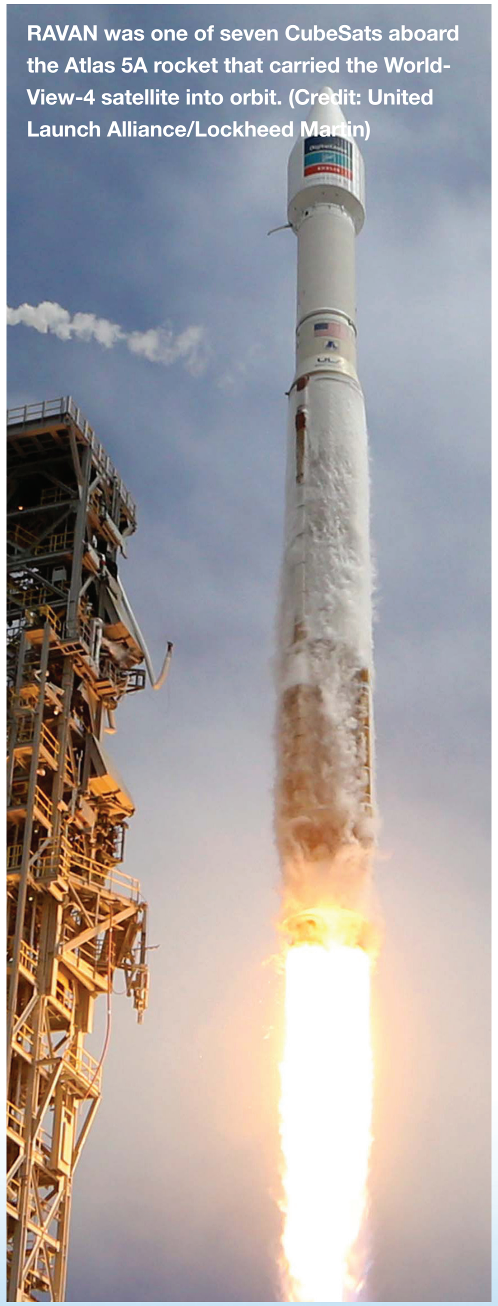
RAVAN CubeSat Launched to Demonstrate New Tech for Radiation Balance Measurements

The Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) CubeSat mission launched on November 11, 2016 as a secondary payload on a ULA Atlas V rocket from Vandenberg Air Force Base.

Developed at Johns Hopkins Applied Physics Lab, with funding through the NASA InVEST program, RAVAN will demonstrate that accurate and critically needed measurements can be made with a small instrument, thanks in part to new carbon nanotube technology that absorbs light extremely efficiently. The RAVAN team will study Earth's radiation imbalance, which is the difference between the amount of energy from the sun that reaches the Earth and that is reflected or radiated back into space.

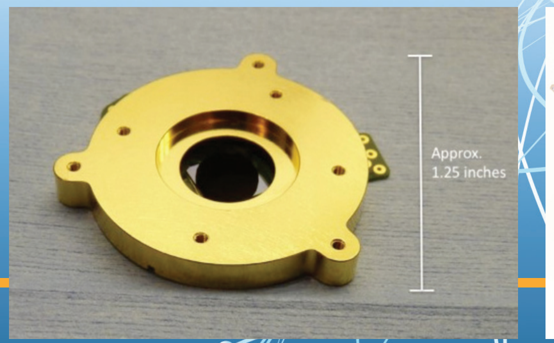
RAVAN features small, accurate radiometers to measure the strength of the Earth's total outgoing radiation across the entire spectrum of energy, from the ultraviolet to the far infrared. Vertically aligned carbon nanotubes (VACNTs) serve as the radiometer's light absorber and will enable the radiometer to gather virtually the full spectrum of light reflected and emitted from Earth.

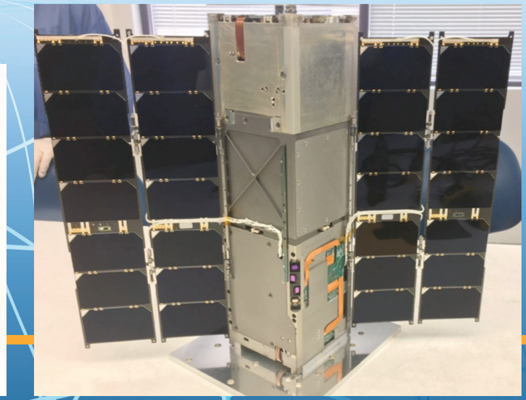
The RAVAN 3U has been fully commissioned and is now acquiring and calibrating data. RAVAN's flight is expected to last up to one year and could eventually lead the way to a constellation of miniature radiometers. Such a constellation could enable global coverage of Earth's radiation budget; provide diurnal sampling of rapidly varying phenomena like clouds, plant life, ozone, and aerosols; and answer long-standing questions about the Earth's climate.



RAVAN was one of seven CubeSats aboard the Atlas 5A rocket that carried the World-View-4 satellite into orbit. (Credit: United Launch Alliance/Lockheed Martin)

Below, Left to Right: Part of the VACNT radiometer, the dark patch in the center is a small "forest" of carbon nanotubes; the RAVAN instrumentation package; and a model of the spacecraft with fully deployed solar panels. (Credits: JHU APL)





Meeting Future Challenges

For over 18 years, ESTO investments have anticipated science requirements to enable many new measurements and capabilities. ESTO technologies were already underway to address the priorities outlined by the 2007 National Academies of Science National Research Council Decadal Survey for Earth Science, the 2014 NASA Science Plan, and NASA's 2010 plan for a climate architecture: "Responding to the Challenge of Climate and Environmental Change." This is a testament to ESTO's broad-based, inclusive strategic planning. It is also the result of a commitment to monitor, and match investments to, the evolving needs of Earth science through engagement with the science community, development of technology requirements, and long-term investment planning.

In 2016, ESTO updated its investment strategies in two key technology areas: Lidar and Microwave remote sensing. With prior strategies nearly a decade old, ESTO solicited community input in order to capture the state of the art in both areas as well as identify emerging technology capabilities and techniques. Virtual, online community forums were held in February and March, and the results were published in Summer 2016.

The *2016 Microwave Technologies Review and Strategy* and the *2016 Lidar Technologies Review and Strategy* are available online at: https://esto.nasa.gov/adv_planning_studies.html

Additional Resources

The ESTO website contains several online resources as well as additional information on ESTO's approach to technology development, programs, validation activities, and strategic planning:

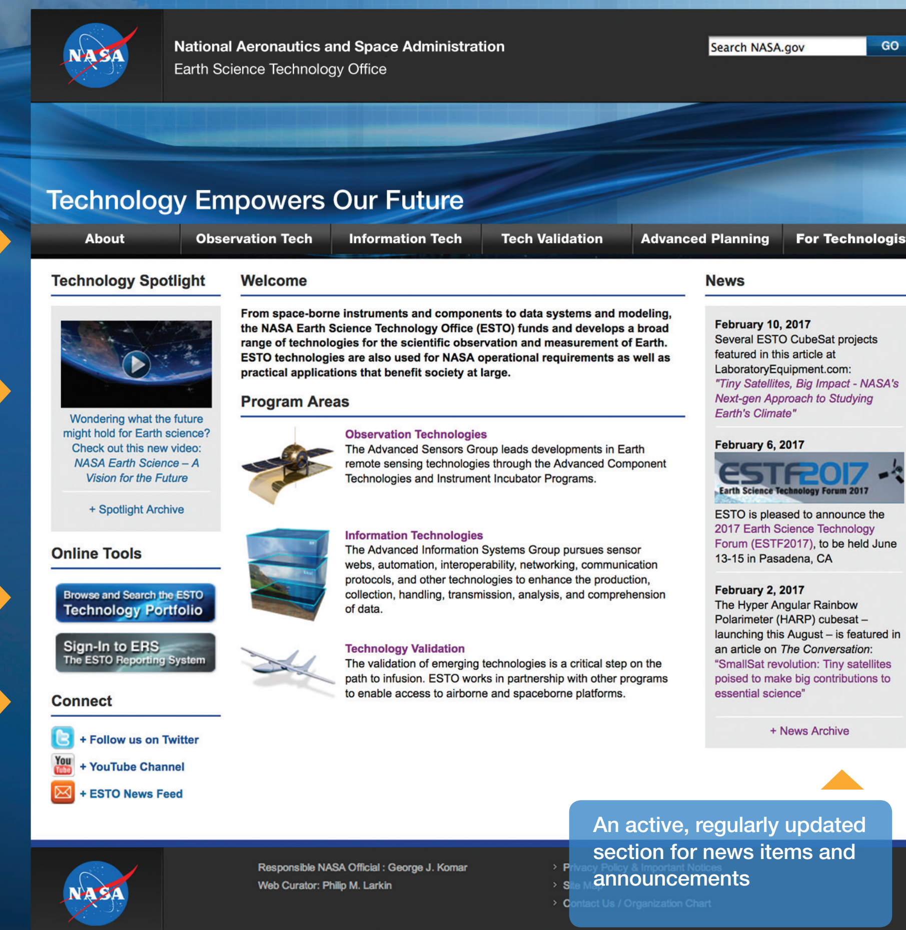
General Information on current and past programs, studies, solicitations, TRL definitions, events, and more.

Timely features on ESTO technology projects, progress, achievements, and infusions

A fully-searchable database of ESTO investments

Social media and news listserv options to stay connected:

> Twitter: @NASAESTO
> YouTube: NASAESTO



An active, regularly updated section for news items and announcements

esto.nasa.gov

National Aeronautics and Space Administration

Earth Science Technology Office
NASA GSFC, Code 407.0
Greenbelt, MD 20771

www.esto.nasa.gov