National Aeronautics and
Space Administration

2017 Annual Report

NASA Earth Science Technology Office

Executive Summary

As you'll read in the pages that follow, 2017 was another full and productive year for technology development at the NASA Earth Science Technology Office (ESTO). Fiscal year 2017 (FY17) saw numerous successes in the selection of new projects and the advancement and infusion of technologies for science. 42 projects completed, and 57% of active ESTO technology projects advanced at least one Technology Readiness Level (TRL) this year.

Also of note, ESTO selected 21 new projects in June through the Advanced Information Systems Technology (AIST) program solicitation and 12 in October 2017 through the Advanced Component Technologies (ACT) program.

As ESTO continues in its 20th year of operation, it will do so on the strong foundation built by its visionary founding director, George Komar, who retired in September. While at ESTO, George built the program to what it is today. He leaves a legacy of responsible investment and credible task management coupled with a perpetual passion for technology advancement. The program he created is regarded throughout NASA and beyond as a benchmark of technology development done well. We wish him the best in his next adventure.

We are pleased to welcome Pamela Millar as the new Director of ESTO. Pam has worked at NASA for 27 years, most recently as the Lead for Flight Validation within ESTO. She has spearheaded the development of several high-profile space demonstration efforts, two of which – the RAVAN and IceCube CubeSats – launched in FY17 (see pages 15-16).

ESTO's successes demonstrate the hard work of our principal investigators and their collaborators. As we welcome the new cohort of AIST and ACT investigators, we look forward to the contributions that they and our existing investigators will bring to ensure a bright future for Earth science.

Robert A. Bauer
Deputy Program Manager

ABOUT ESTO

As the technology development 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:

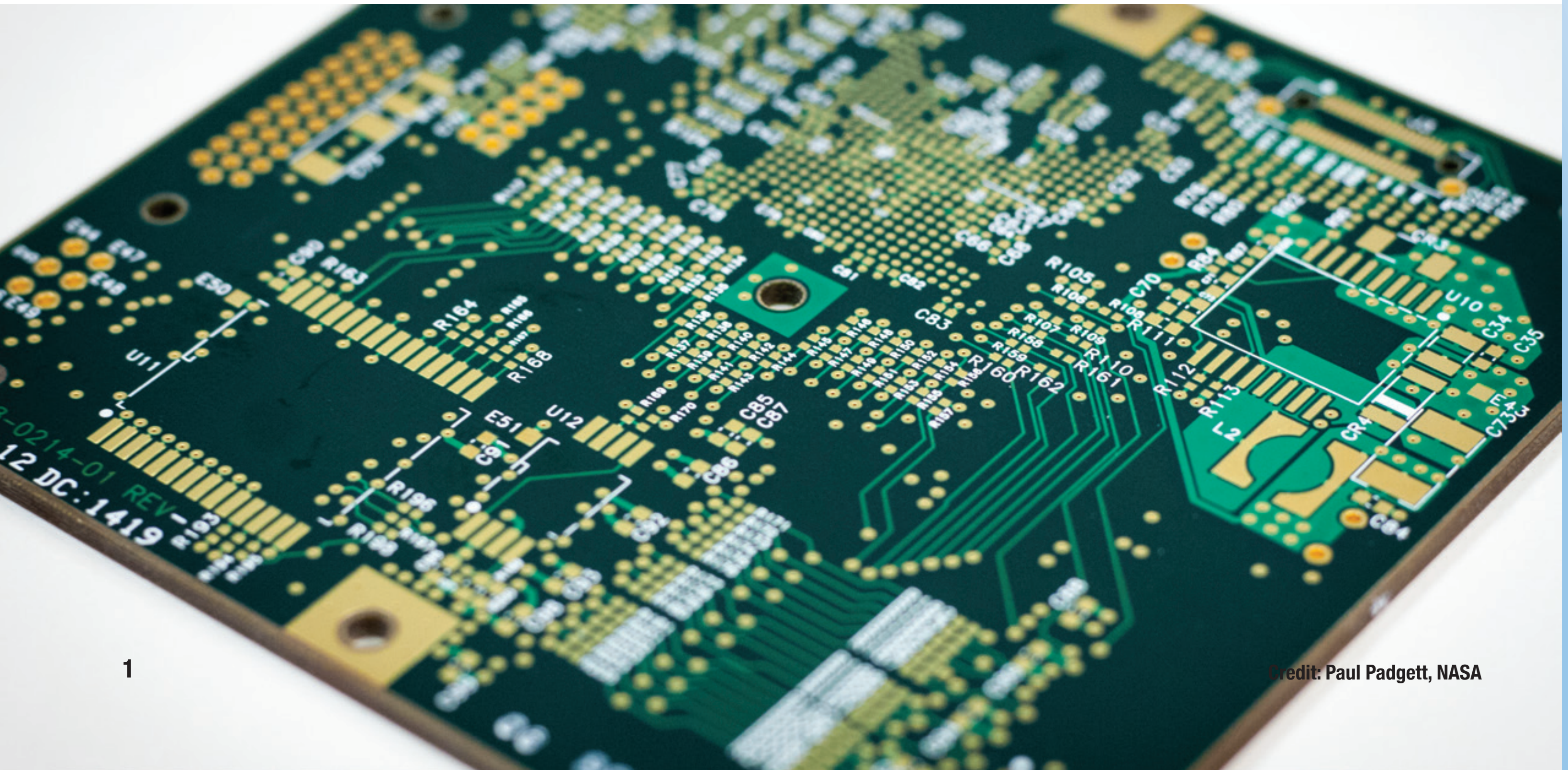
- Planning investments by careful analyses of science requirements
- Selecting and funding technologies through competitive solicitations and partnership opportunities
- Actively managing the progress of funded projects
- Facilitating the infusion of mature technologies into science measurements

The results speak for themselves: a broad portfolio of well over 800 emerging technologies – 141 of which were active at some point during FY17 – ready to enable or enhance new science measurement capabilities as well as other infusion opportunities.

Observation Technology

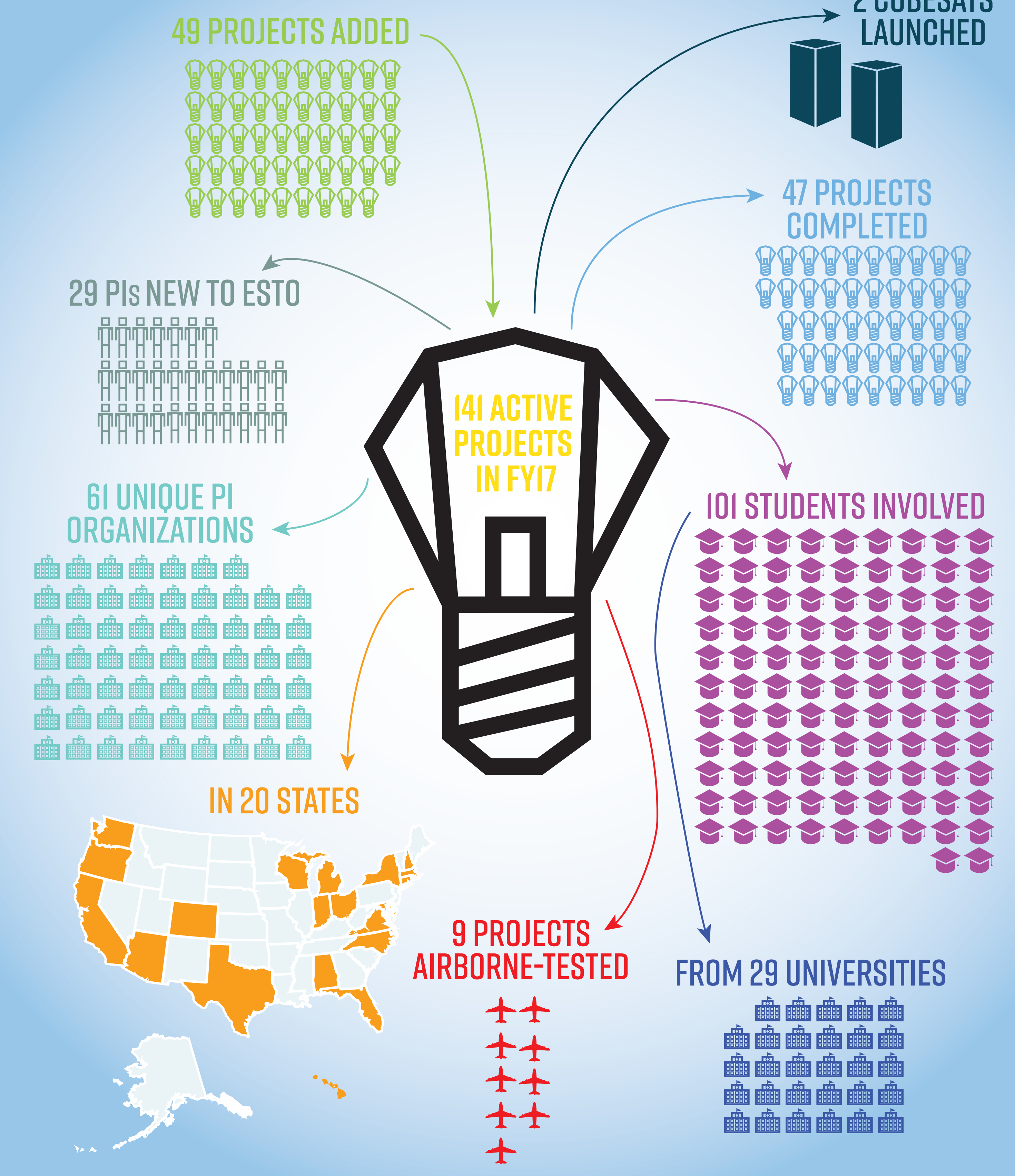
Information Technology

Technology Validation



Credit: Paul Padgett, NASA

ESTO FY17: BY THE NUMBERS



2017 METRICS

With 775 completed technology investments and a portfolio during FY17 (October 1, 2016, through September 30, 2017) of 141 active projects, ESTO drives innovation, enables future Earth science measurements, and strengthens NASA's reputation for developing and advancing leading-edge technologies.

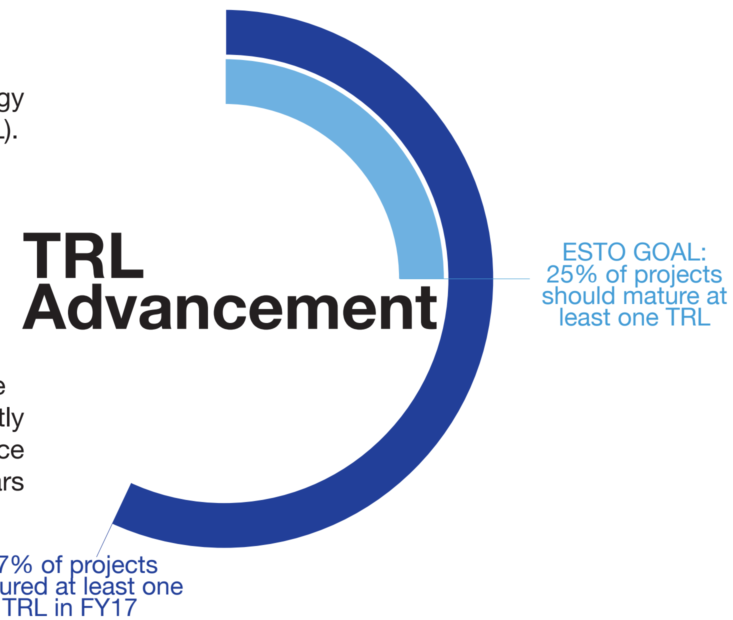
To clarify ESTO's FY17 achievements, what follows are the year's results tied to NASA's performance metrics for ESTO:

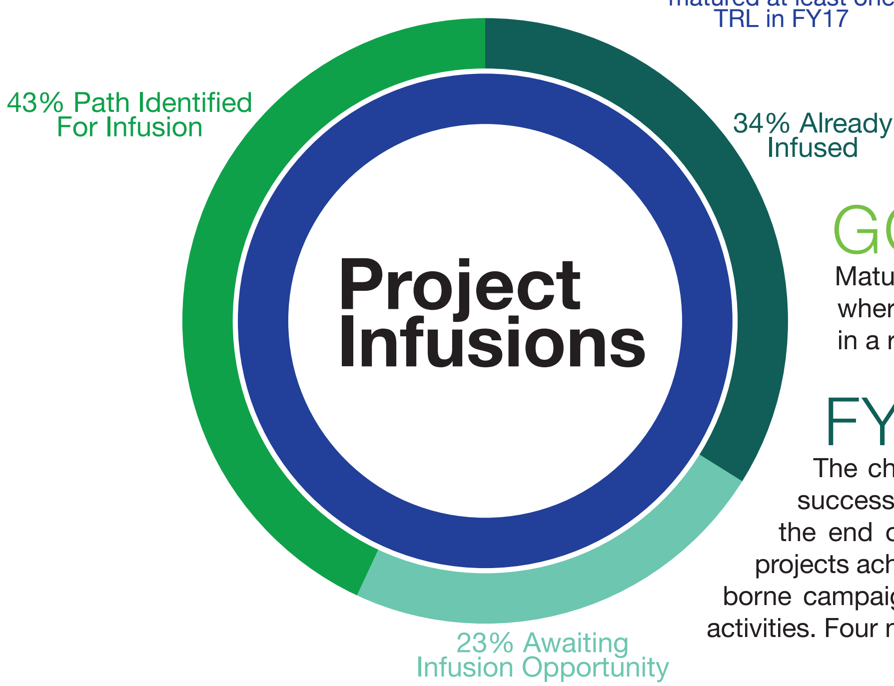
GOAL 1:

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

FY17 RESULT:

57% of ESTO technology projects funded during FY17 advanced one or more TRLs over the course of the fiscal year. 16 of these projects advanced more than one TRL. Although the percentage of TRL advancements tends to be higher in years with large numbers of completing projects, ESTO has consistently met or exceeded this metric in every fiscal year since inception. The average TRL advancement for all years going back to 1999 is 41%.





GOAL 2:

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

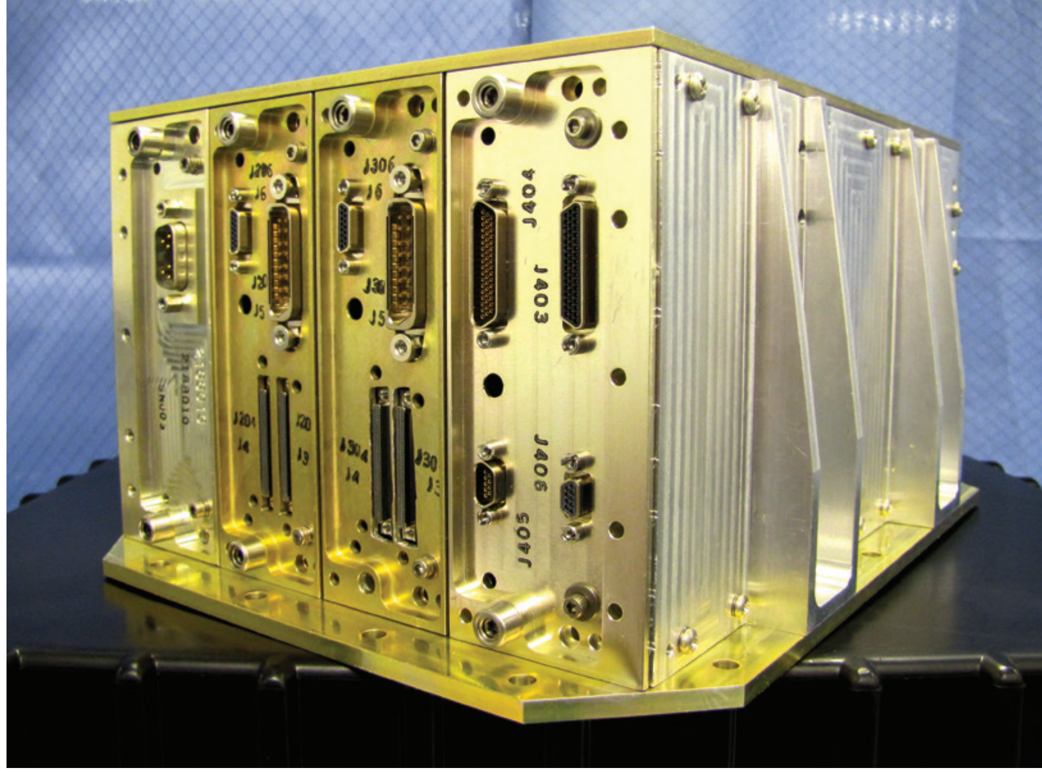
FY17 RESULT:

The chart to the left shows ESTO's all-time infusion success drawn from 775 completed projects through the end of FY17. In this fiscal year, at least 10 ESTO projects achieved infusion into science measurements, airborne campaigns, data systems, or follow-on development activities. Four notable examples follow.

SpaceCube 2.0

SpaceCube 2.0 is an in-flight reconfigurable Field Programmable Gate Array (FPGA) based processing system that can provide 10x to 100x improvements in on-board computing power while lowering relative power consumption and cost (PI: Tom Flatley, NASA GSFC).

The technology has already been infused into multiple applications, including as the instrument processor for an ESTO-funded spectrometer measuring atmospheric methane on board the International Space Station. NASA's Satellite Servicing Projects Division has chosen SpaceCube 2.0 to be its on-board processor for a variety of projects, including the Robotic Refueling Mission-3 (RRM3), the Restore-L Robotic Servicing Mission, and the Asteroid Redirect Robotic Mission (ARRM).



HySICS

In 2013 and 2014, the HyperSpectral Imager for Climate Science (HySICS, Greg Kopp, University of Colorado LASP) was demonstrated on two high-altitude balloon flights and made ultraviolet-to-solar irradiance measurements (350-2300 nm wavelength range) of Earth, cross-calibrated by periodic measurements of the sun. The flights achieved the most accurate solar radiance measurements – calibrated to the Sun to better than 0.2 percent radiometric accuracy – that have ever been made of the Earth. The instrument is now undergoing further development to become the Reflected-Solar instrument on board the NASA Climate Absolute Radiance and Refractivity Observatory (CLARREO) Pathfinder mission, slated to launch to the International Space Station in 2021.

TIMS

The Geostationary Carbon Cycle Observatory (GeoCARB), a NASA Earth Venture Mission launching in 2022, will utilize Tropospheric Infrared Mapping Spectrometers (TIMS, PI: John Kumer, Lockheed Martin, IIP-04) for atmospheric carbon monoxide profile measurements. Developed from 2005-2008, the TIMS instruments were miniaturized versions of previous spectrometer designs and were demonstrated in ground tests in 2007. GeoCARB will utilize the technology to investigate the natural sources, sinks, and exchange processes that control carbon dioxide, carbon monoxide, and methane in the atmosphere.

It is with great sadness that we report the passing of John "Jack" Kumer on July 26, 2017, in Palo Alto, CA.

ABOVE: The 20cm x 25cm x 13cm SpaceCube 2.0. Credit: NASA

LEFT: Operating from a gondola platform, the HySICS flew at close to 120,000 feet for over 8 hours to demonstrate a solar cross-calibration approach and to acquire sample Earth and lunar radiances in an effort to improve climate change models. Credit: NASA Balloon Program Office

2017 METRICS (cont.)

HAMMR

Sentinel-6 – a four-partner mission among NASA, ESA, EUMETSAT and NOAA – will include new technology to correct radar altimetry signals for wet-tropospheric path delay over coastal regions, rivers, and lakes. The new High-Resolution Microwave Radiometer (HRMR), in concert with the Advanced Microwave Radiometer (AMR-C), will be used to correct signal delay in areas with significant tropospheric water vapor. HRMR is an internally calibrated, direct-detection radiometer (90, 130 and 168 GHz) that was enabled by earlier IIP and ACT technology investments, particularly the High-frequency Airborne Microwave and Millimeter-wave Radiometer (HAMMR; PI: Reising, Colorado State, in collaboration with the Jet Propulsion Laboratory, IIP-10 and ACT-08). HAMMR is a multi-channel airborne microwave radiometer that includes the 90, 130, and 168 GHz bands to demonstrate wet tropospheric path delay measurements and was originally targeted for the NASA SWOT mission concept. First flown in 2014 on board a Twin Otter aircraft, HAMMR demonstrated high spatial-resolution performance and verified a high-frequency retrieval algorithm.

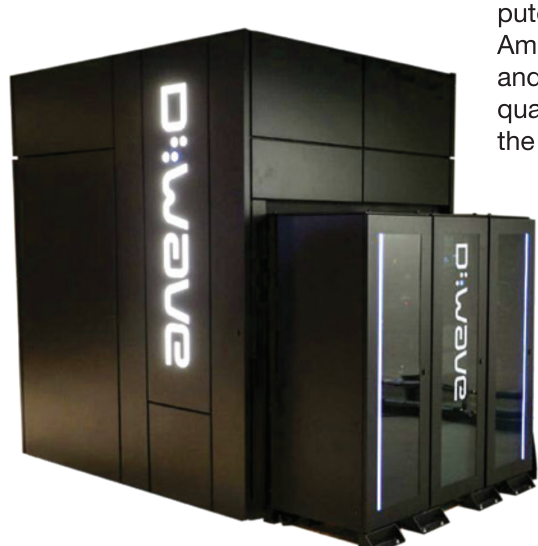
GOAL 3:

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

FY17 RESULT: Estimating Carbon Fluxes with Quantum Computing

When NASA launched the Orbiting Carbon Observatory-2 (OCO-2) in 2014, it marked the first time a US satellite could directly measure global-scale surface CO2 data and sun-induced fluorescence (plant greenness) with 1 to 3 km resolution – high enough to glean ecosystem-scale net sources and sinks. But calculating the net annual difference of photosynthetic and respiratory terrestrial CO2 flux exchange over the entire Earth's surface at 1 km is computationally challenging, akin to picking out a face in a crowded stadium. What if there was a way to accurately quantify and speed such calculations so that we can pinpoint areas of unusual carbon flux?

To answer that question, an ESTO-funded team led by Milton Halem of the University of Maryland, Baltimore County (UMBC) set out to study the feasibility of Quantum Annealing – a type of Quantum Computing useful for machine learning applications – for estimating carbon fluxes, sources or sinks, from OCO-2 datasets. Quantum Annealing uses optimization and random sampling to quickly find a "solution" – in this case an anomalous carbon dioxide measurement – within a discrete area.



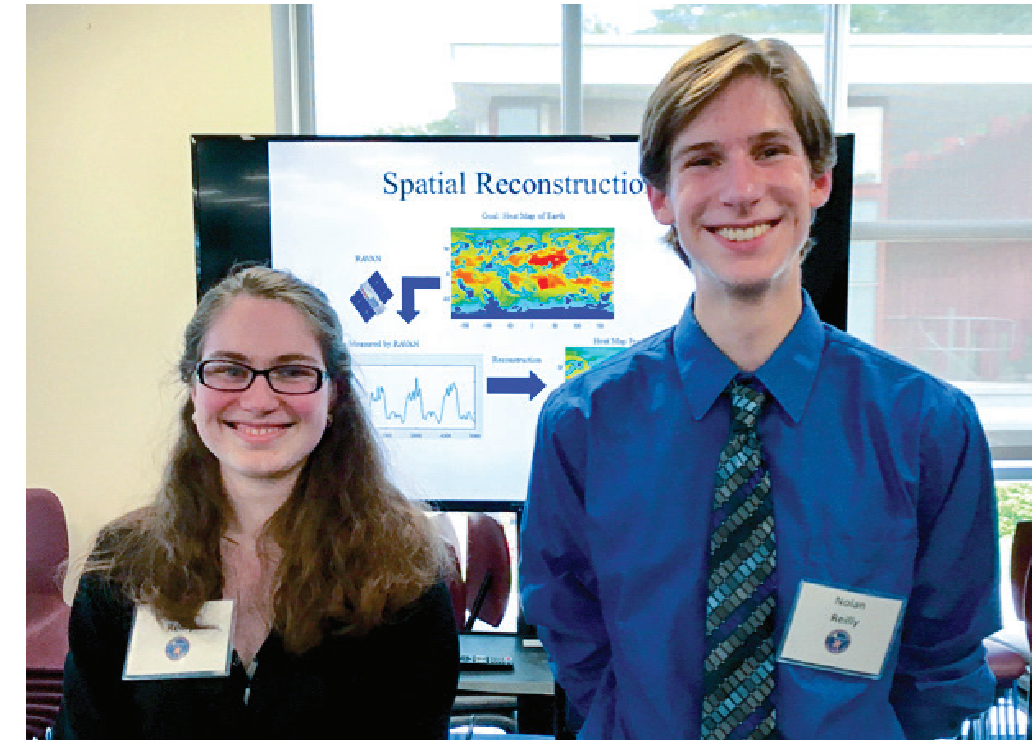
Halem's team at UMBC, NASA Goddard Space Flight Center, Science Applications International Corporation (SAIC), and Columbia University used the NASA/Google/USRA D-Wave 2X quantum annealing computer (shown here) located at NASA Ames Research Center to explore and apply newly developed hybrid quantum annealing algorithms with the OCO-2 data. Their work has produced monthly global estimates of turbulent carbon flux inferences at sites near Oklahoma City and has also led to implementation of new quantum machine learning strategies.

Just as this new technique works to more-easily and more-quickly identify carbon flux, it may also improve analysis for a variety of other datasets, such as changes in soil moisture. The project has opened the door to Quantum Annealing for satellite data across the Earth and space sciences. With a new round of funding through ESTO's 2016 Advanced Information Systems Technology solicitation, the project team is now working to make enhancements and move the capability into an operational phase.

Student Participation

As with many research and development projects, students are integral to the work and success of technology development teams. Since ESTO's founding, 757 students from over 130 institutions have worked on the Program's various projects. Often, these students have gone on to work in the aerospace industry aided by their experience supporting ESTO's various tasks.

In FY17, 101 students were involved with active ESTO projects. Most typically, these students are pursuing undergraduate and graduate degrees, but occasionally high school students also join in on the technology development work.



Fraternal twins Sonia and Nolan Reilly supported the RAVAN mission by developing an optimization routine for reconstructing potential data for a spatial map of heat flux. Credit: Bill Swartz, The Johns Hopkins University Applied Physics Laboratory

STUDENT SPOTLIGHT:

Two such students, Sonia and Nolan Reilly, supported the RAVAN (Radiometer Assessment using Vertically Aligned Nanotubes) CubeSat project led by Bill Swartz of The Johns Hopkins Applied Physics Laboratory (APL) while in their final year of high school through the ASPIRE (APL's Student Program to Inspire, Relate & Enrich) internship program.

Fraternal twins, Sonia and Nolan used their strong interest in mathematics to help extract spatial information from RAVAN's averaged data, write software to simulate the data the satellite could collect, and developed an optimization routine to best reconstruct the data for a spatial map of heat flux.

Now in college earning S.B. degrees in Mathematics with Computer Science from MIT, Sonia and Nolan are using what they learned as part of the RAVAN team to shape their career goals. Of this, Sonia said, "My research at APL was in fact exactly the sort of work that I could see myself doing as a career." She went on to say that by working on RAVAN she was able to learn about the "mathematics of remote sensing as well as about the scientific context of my project, the logistics of satellite launch, new CubeSat technologies, and a range of other things" that wouldn't have been possible in class alone.

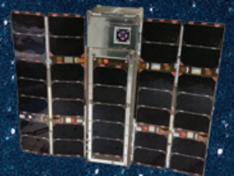
Their work using mathematics and computer science to improve remote sensing didn't end with their ASPIRE internships. They continued on as valuable members of the RAVAN project as college interns after they finished high school and hope to return to APL next summer, new skills in hand, to continue supporting the RAVAN mission.

ESTO's CUBESATS

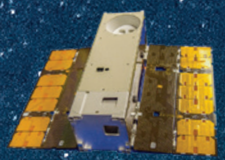
A persistent issue has dogged spaceborne instruments: there's really no way to fully test them here on Earth. Given the cost of a typical space mission, launching an untested system into orbit is an expensive (and potentially risky) way to validate new technologies. CubeSats change this paradigm by providing a rapid and low-cost method of getting new technologies into space for validation. ESTO has launched six of these toaster-sized micro-satellites and has another seven on deck ready to validate a wide range of exciting new Earth science technologies.

CUBESAT ON-BOARD PROCESSING VALIDATION EXPERIMENT (COVE)
Launched: 28 OCT 2011
PI: Paula J. Pingree, Jet Propulsion Laboratory (JPL)
Mission: Demonstrate an on-board processing system to optimize the data processing and instrument design of a multi-angle SpectroPolarimetric Imager for the ACE Decadal Survey Mission concept.

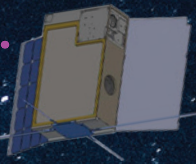
GEO-CAPE ROIC IN-FLIGHT PERFORMANCE EXPERIMENT (GRIFEX)
Launched: 31 JAN 2015
PI: David Rider, JPL
Mission: Verify spaceborne performance of a state-of-the-art ROIC/ Focal Plane Array with in-pixel digitization and an unprecedented frame rate.



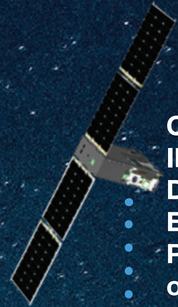
ICECUBE
Launched: 16 MAY 2017
PI: Dong Wu, NASA Goddard Space Flight Center
Mission: To develop and validate a commercially available flight-qualified 883-GHz receiver to enable future cloud ice remote sensing from space.



MICROWAVE RADIOMETER TECHNOLOGY ACCELERATION (MiRaTA)
Estimated Launch: NOV 2017
PI: Kerri Cahoy, MIT
Mission: To validate new microwave radiometer and GPS Radio Occultation technology capable of measuring temperature, humidity and cloud ice.



COMPACT INFRARED RADIOMETER IN SPACE (CIRiS)
Estimated Launch: 2018
PI: David Osterman, Ball Aerospace & Technologies Corporation
Validate in space an infrared imaging radiometer that uses an uncooled microbolometer and carbon nanotube calibration source.

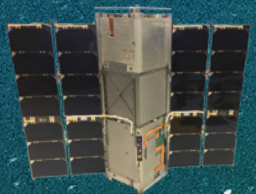


COMPACT SPECTRAL IRRADIANCE MONITOR FLIGHT DEMONSTRATION (CSIM-FD)
Estimated Launch: 2018
PI: Erik Richard, LASP/University of Colorado Boulder
Mission: Validate a compact, cost-effective, low-risk solar spectral irradiance monitor with high calibration accuracy and improved performance stability.

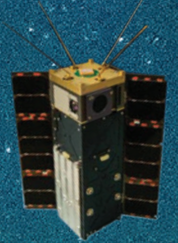
2011 | 2013 | 2015 | 2017 | 2018 & Beyond

COVE RE-FLIGHT
Launched: 5 DEC 2013
PI: Paula J. Pingree, JPL
Mission: Finalize COVE's initial mission after a deployment issue prevented CubeSat operation.

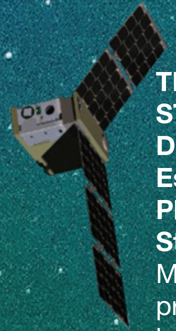
INTELLIGENT PAYLOAD EXPERIMENT (IPEX)
Launched: 5 DEC 2013
PI: Steve Chien, JPL
Mission: Validate direct broadcast, autonomous science, and product delivery technologies supporting the Intelligent Payload Module (IPM) for the Hyperspectral Infrared Imager Mission concept.



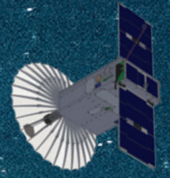
RADIOMETER ASSESSMENT USING VERTICALLY ALIGNED NANOTUBES (RAVAN)
Launched: 11 NOV 2016
PI: Bill Swartz, Johns Hopkins Applied Physics Laboratory
Mission: Build a radiometer using Vertically Aligned Carbon Nanotubes and demonstrate the instrument's effectiveness in measuring Earth's total outgoing radiation.



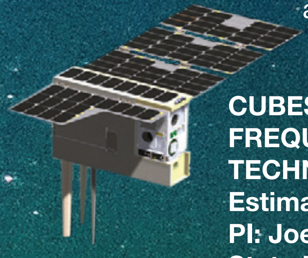
HYPER-ANGULAR RAINBOW POLARIMETER (HARP)
Estimated Launch: MAY 2018
PI: J. Vanderlei Martins, University of Maryland, Baltimore County
Mission: To validate the in-flight capabilities of a highly accurate and precise wide field of view hyperangular polarimeter for characterizing aerosol and cloud properties.



TEMPORAL EXPERIMENT FOR STORMS AND TROPICAL SYSTEMS DEMONSTRATION (TEMPEST-D)
Estimated Launch: MAY 2018
PI: Steve Reising, The Colorado State University
Mission: Improve understanding of cloud processes vital to climate change prediction by demonstrating a radiometer measuring five frequencies from 89 to 182 GHz on a 6U spacecraft.



RAINCUBE
Estimated Launch: MAY 2018
PI: Eva Peral, JPL
Mission: Enable future rainfall profiling radar missions on low-cost, quick-turnaround platforms through development, launch, and operation of the first Ka-band rain-profiling radar instrument on a 6U CubeSat.



CUBESAT RADIOMETER RADIO FREQUENCY INTERFERENCE TECHNOLOGY (CubeRRT)
Estimated Launch: MAY 2018
PI: Joel Johnson, The Ohio State University
Mission: Demonstrate wideband radio frequency interference mitigating backend technology for future spaceborne microwave radiometers operating at 6 to 40 GHz.

LEGEND
Pre-InVEST
InVEST-12
InVEST-15
EVI-TECH
Other

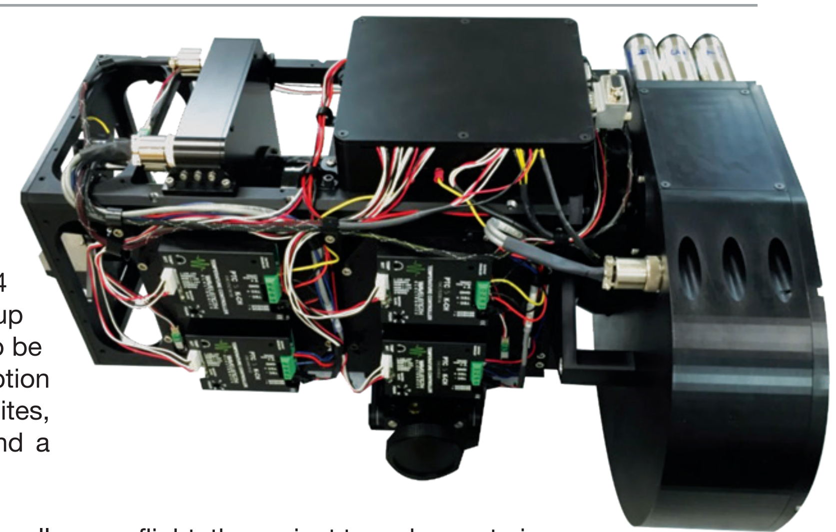
Observation Tech: IIP

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.

With more than 40 projects active in FY17, IIP has continued to pursue a diverse portfolio of promising technologies that aim to improve the performance of active and passive instruments and sensors. Three projects graduated from IIP in 2017, all of which advanced at least 1 TRL over their lifetime:

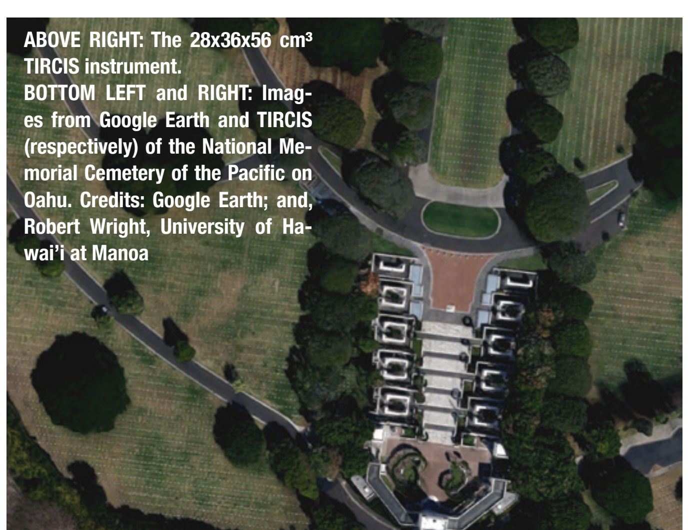
- *Development of a Compact Solar Spectral Irradiance Monitor with High Radiometric Accuracy and Stability (CSIM)* – Erik Richard, University of Colorado Boulder
- *Ka-band Doppler Scatterometer for Measurements of Ocean Vector Winds and Surface Currents (DopplerScatt)* – Dragana Perkovic-Martin, Jet Propulsion Lab
- *Enhancement, Demonstration, and Validation of the Wideband Instrument for Snow Measurements (WISM)* – Tim Durham, Harris Corporation

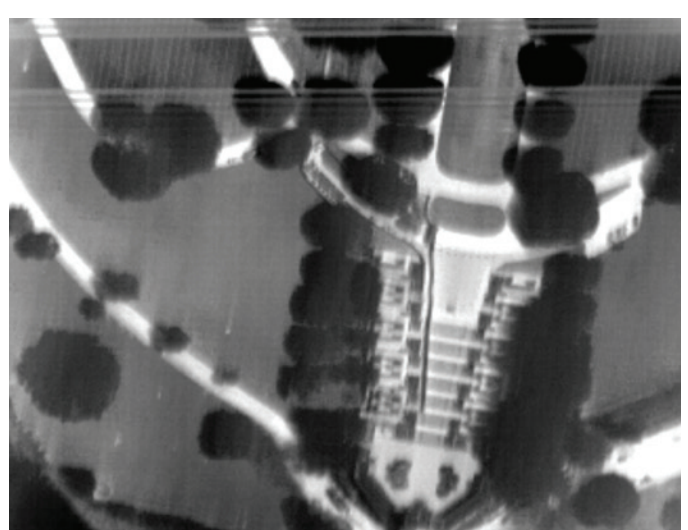
PROJECT SPOTLIGHT: First Flights for New Thermal Infrared Instrument



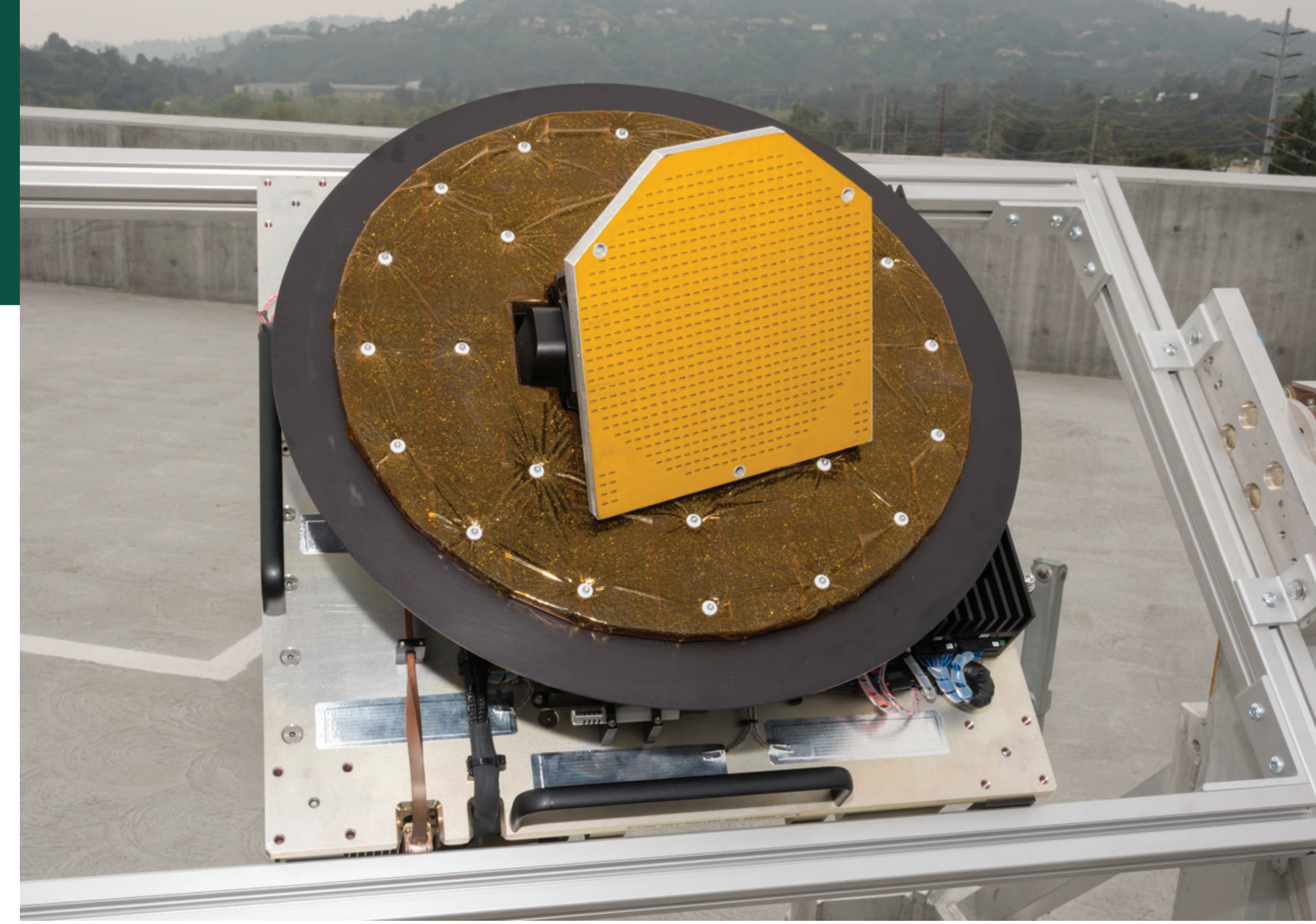
The Thermal Infrared Compact Imaging Spectrometer (TIRCIS, PI: Robert Wright, Univeristy of Hawai'i at Manoa) is a novel measurement concept for hyperspectral thermal infrared (TIR; 8-14 μm) providing image data at a spectral resolution of up to 8 cm^{-1}, or up to 50 spectral channels. Designed to be of sufficiently low mass, volume, and power consumption to be eventually deployed on smaller micro-satellites, TIRCIS consists of a Fabry-Perot interferometer and a microbolometer array that does not require cooling.

In February 2017, TIRCIS was integrated onto a small private aircraft in Hawaii (a Piper Navajo operated by Air Flight Service Inc.) and began a series of test flights over a variety of landscape types. The first flight of approximately three hours took place over test targets on the island of Oahu. Additional flights are planned over the Kilauea volcano on the island of Hawaii. During the volcano overflight, the project team hopes to image the gas plume from the volcano as well as active lava flows in order to establish how well TIRCIS can quantify sulfur dioxide fluxes. Beyond volcanoes, there are numerous applications for this kind of spatially-resolved TIR data – from wildfire characterization to water resource management to mineral exploration.





ABOVE RIGHT: The 28x36x56 cm^3 TIRCIS instrument.
BOTTOM LEFT and RIGHT: Images from Google Earth and TIRCIS (respectively) of the National Memorial Cemetery of the Pacific on Oahu. Credits: Google Earth; and, Robert Wright, University of Hawai'i at Manoa



ABOVE: The DopplerScatt radar at JPL before being attached to the bottom of a King Air B200 plane. Credit: NASA/JPL-Caltech

PROJECT SPOTLIGHT: DopplerScatt Makes a SPLASH

In April and May of 2017, several organizations teamed up for the Submesoscale Processes and Lagrangian Analysis on the Shelf (SPLASH) campaign, an effort to investigate the movement of potential oil spills and leaks in the Gulf of Mexico. Led by the Consortium for Advanced Research on Transport of Hydrocarbon in the Environment (CARTHE), SPLASH also included a new airborne instrument called DopplerScatt which can make measurements of surface winds and water currents.

Built at the Jet Propulsion Laboratory with funding from IIP, DopplerScatt is a Ka-band Doppler scatterometer that flew for the first time in 2016 over coastal Oregon and Washington. The instrument's ability to take simultaneous measurements of ocean surface winds and water currents is a new science capability, one that could improve our understanding of air-sea interactions and their influence on heat transport, surface momentum, gas fluxes, ocean productivity, and marine biology.

For the SPLASH campaign, the DopplerScatt team, led by Dragana Perkovic-Martin of JPL, installed the instrument on a King Air B200 aircraft and flew it over the coastal shelf off the U.S. Gulf Coast. DopplerScatt's measurements complimented in situ data gathered by hundreds of drifting floats and ship-born instruments as well as high-resolution model outputs from the U.S. Naval Research Laboratory. The CARTHE team used DopplerScatt to decide where to place the drifters, and the models and in situ instruments were in turn used to further validate DopplerScatt measurements.

While DopplerScatt can be used on future NASA airborne science missions, the technology development also lays the groundwork for an eventual spaceborne instrument, making global measurements of ocean surface winds and water currents simultaneously for the first time.

Observation Tech: ACT

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.

PROJECT SPOTLIGHT: Beamsteerable GNSS Radio Occultation ASIC

In FY17, the ACT program held 10 investments, one of which completed after advancing 2 TRLs: *Beamsteerable GNSS Radio Occultation ASIC* - Michael Shaw, GigOptix.

This recently completed ACT project has designed, fabricated, and tested a new ASIC (Application Specific Integrated Circuit) intended for high-quality radio occultation (RO) weather observations using signals from the Global Navigations System Satellite (GNSS) constellations. RO measurements are made when a satellite receives the radio transmissions from GNSS satellites through the limb of the atmosphere. Information about atmospheric temperature, pressure and water content can be derived from the refraction of the signal as it passes through the atmosphere.

The small, low-power ASICs would be easier to accommodate on missions of opportunity and could enable constellations of small satellites that could provide more frequent coverage and improve weather prediction. The design supports four radio frequency (RF) inputs capable of receiving three GNSS signals per input in a single ASIC, allowing reception of all known GNSS networks worldwide. Multiple RF channels on a GNSS receiver is a unique feature which could also enable precision beam forming; large beam forming arrays may provide the necessary signal to noise ratio to produce ocean altimetry and scatterometry observations.

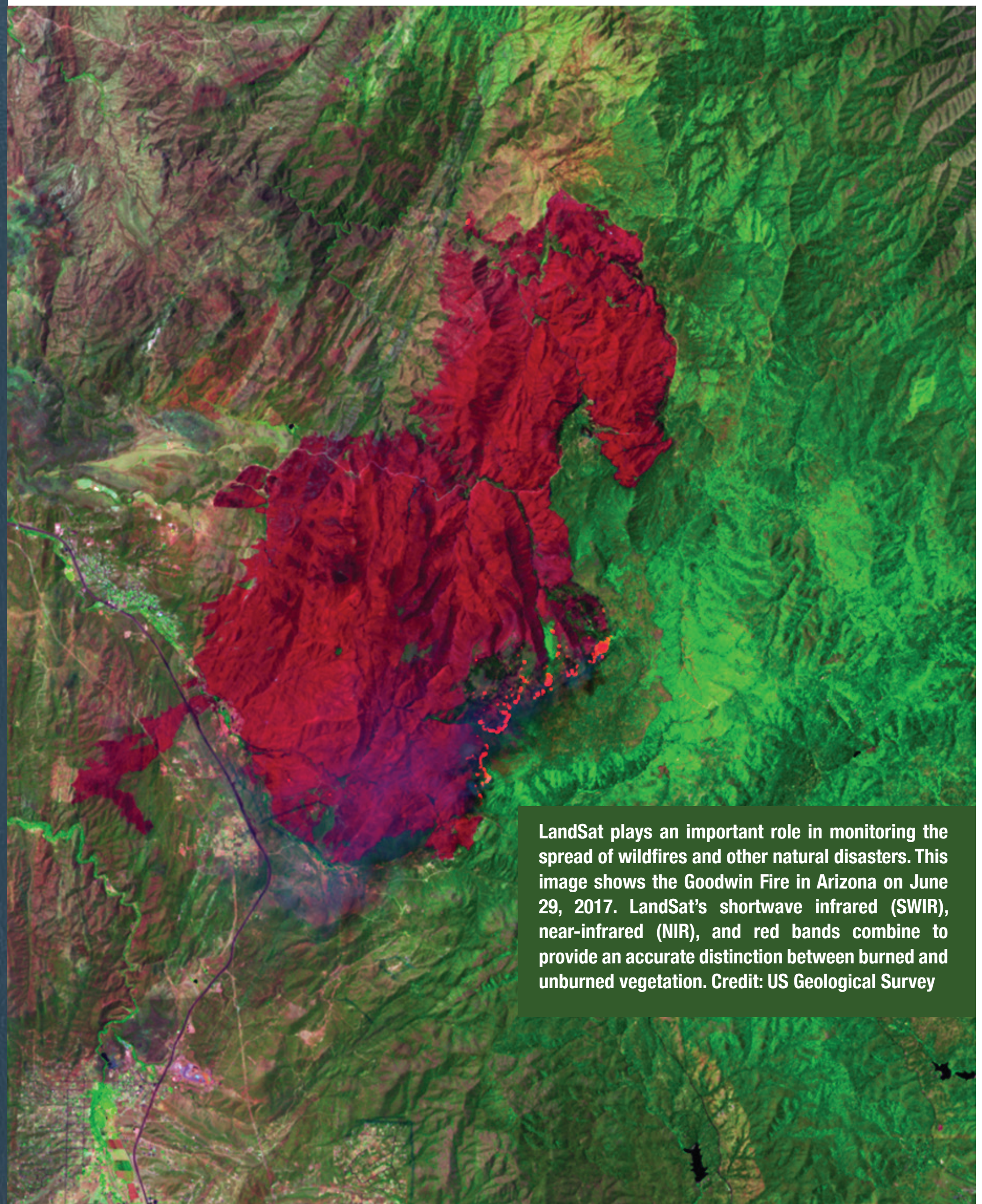
To verify its performance, the project team integrated and tested the ASIC chip using a simulator and a beamsteerable antenna. In their testing, they found the group delay and phase stability to be an order of magnitude better than current receivers.

The large circuit board on the left is a previous ASIC design. The three rectangular segments provide 3 antenna inputs, supporting four-20 MHz channels, and require approximately 5 W of power. To its right is the new ASIC chip. By adding a few small components, such as connectors, it will provide 3 antenna inputs, with the equivalent of twelve-40 MHz channels, and require only 1 W of power. Credit: Michael Shaw, GigOptics, Inc.

Observation Tech: SLI-T

For over 40 years, the Landsat series of satellites have been providing a continuous stream of moderate resolution, multispectral images that have been used by a broad range of specialists to analyze our world. From natural resource management to land cover research, this long-running data set is unmatched in quality, detail, coverage and value, and it provides unparalleled information about our Earth.

To continue the mission of Landsat, NASA initiated the Sustainable Land Imaging – Technology (SLI-T) program to explore innovative new technologies to achieve Landsat-like data with more efficient instruments, sensors, components and methodologies. ESTO currently supports six projects focused on science enhancement and reductions in instrument volume, mass and power usage.

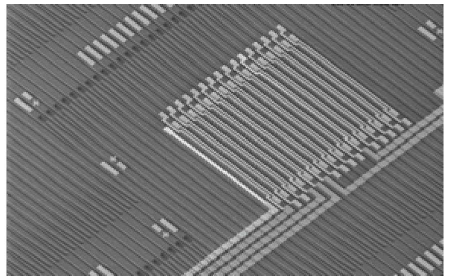


LandSat plays an important role in monitoring the spread of wildfires and other natural disasters. This image shows the Goodwin Fire in Arizona on June 29, 2017. LandSat's shortwave infrared (SWIR), near-infrared (NIR), and red bands combine to provide an accurate distinction between burned and unburned vegetation. Credit: US Geological Survey

PROJECT SPOTLIGHT: Integrated Photonic Imaging Spectrometer

A team at Northrup Grumman Systems Corporation led by Stephanie Sandor-Leahy is pursuing a new integrated photonic imaging spectrometer that aims to be 7 times lighter and 25 times smaller than current instruments. To accomplish these reductions, the project is employing lithographically patterned photonic waveguide technology, which enables image acquisition in spectral bands and modes that surpass current Landsat capabilities. The planned instrument design will be manufactured using standardized, repeatable processes, enabling rapid and inexpensive reproduction and making the technology more viable for commercial applications like agriculture, biomedicine and consumer electronics.

BELOW: A scanning electron microscope image of the photonics waveguide on a silicon wafer.
BOTTOM: A close-up view of a 100 mm silicon waveguide wafer. Several 3-mil indium gallium arsenide photodetector chipsets were successfully integrated onto the wafer. Credits: Stephanie Sandor-Leahy, Northrup Grumman



Information Tech: AIST

Advanced information systems play a critical role in the collection, handling, and management of the vast amounts of Earth science data, both in space and on the ground. Advanced computational systems and technology concepts that enable the capture, transmission, and dissemination of terabytes of data are essential to NASA's vision of a distributed observational network. ESTO's Advanced Information Systems Technology (AIST) program employs an end-to-end approach to develop these critical technologies—from the space segment, where the information pipeline begins, to the end user, where knowledge is advanced.

NEW PROJECTS AWARDED

The AIST program included 47 active projects in FY17, 22 of which were selected in June through a competitive solicitation. These new awards are:

- *NeMO-Net: The Neural Multi-Modal Observation & Training Network for Global Coral Reef Assessment* - Ved Chirayath, NASA Ames Research Center
- *Climate Risks in the Water Sector: Advancing the Readiness of Emerging Technologies in Climate Downscaling and Hydrologic Modeling* - Martyn Clark, National Center for Atmospheric Research
- *VISAGE: Visualization for Integrated Satellite, Airborne, and Ground-Based Data Exploration* - Helen Conover, The University of Alabama in Huntsville
- *Autonomous Moisture Continuum Sensing Network* - Dara Entekhabi, Massachusetts Institute of Technology
- *SpaceCubeX: On-board processing for Distributed Measurement and Multi- Satellite Missions* - Matthew French, University Of Southern California
- *Computational Technologies: An Assessment of Hybrid Quantum Annealing Approaches for Inferring and Assimilating Satellite Surface Flux Data into Global Land Surface Models* - Milton Halem, University of Maryland, Baltimore County
- *Simulation-Based Uncertainty Quantification for Atmospheric Remote Sensing Retrievals* - Jonathan Hobbs, Jet Propulsion Laboratory
- *Software Workflows and Tools for Integrating Remote Sensing and Organismal Occurrence Data Streams to Assess and Monitor Biodiversity Change* - Walter Jetz, Yale University
- *Enabling Multi-Platform Mission Planning and Operations Simulation Environments for Adaptive Remote Sensors* - Joel Johnson, The Ohio State University
- *Estimations of Fuel Moisture Content for Improved Wildland Fire Spread Prediction* - Branko Kosovic, National Center for Atmospheric Research
- *Generalizing Distributed Missions Design Using the Trade-Space Analysis Tool for Constellations (TAT-C) and Machine Learning (ML)* - Jacqueline Le Moigne, NASA Goddard Space Flight Center
- *Multi-Instrument Radiative Transfer and Retrieval Framework* - James McDuffie, JPL
- *Advanced Phenological Information System* - Jeffrey Morisette, USGS Fort Collins Science Center
- *Automated Protocols for Generating Very High-Resolution Commercial Validation Products with NASA HEC Resources* - Christopher Neigh, NASA GSFC
- *Computer Aided Discovery and Algorithmic Synthesis for Spatio-Temporal Phenomena in InSAR* - Victor Pankratius, Massachusetts Institute of Technology
- *Simplified, Parallelized InSAR Scientific Computing Environment* - Paul Rosen, JPL
- *Generative Models to Forecast Community Reorganization with Climate Change* - Jennifer Swenson, Duke University
- *Spectral Data Discovery, Access and Analysis through EcoSIS Toolkits*- Philip Townsend, University of Wisconsin-Madison
- *Framework for Mining and Analysis of Petabyte-Size Time-Series on the NASA Earth Exchange (NEX)* - Andy Michaelis, NASA Ames Research Center
- *HY-LaTiS: Evolving the Functional Data Model through Creation of a Tool Set for Hyperspectral Image Analysis* - Anne Wilson, University of Colorado Boulder
- *JAWS: Justified AWS-Like Data through Workflow Enhancements that Ease Access and Add Scientific Value* - Charlie Zender, University of California, Irvine
- *A Science and Applications Driven Mission Planning Tool for Next Generation Remote Sensing of Snow* - Barton Forman, University of Maryland, College Park

BELOW: Petya Campbell of the University of Maryland, Baltimore County and NASA GSFC tested an existing spectrometer from a hexicopter platform as part of her AIST-14 project. Her team is developing and demonstrating machine learning-enhanced software that will advance the approach for semiautonomously producing and disseminating spectral data important for vegetation monitoring. Campbell has demonstrated significant progress towards autonomy of UAV measurements including the ability to adjust calibration and flight plans, literally, on the fly. Credit: Petya Campbell, University of Maryland, Baltimore County

PROJECTS COMPLETED

21 AIST projects completed this year, 18 of which advanced at least 2 TRLs over their course of funding. The FY17 AIST graduates are as follows:

- *Global Flood Risk From Advanced Modeling and Remote Sensing in Collaboration With Google Earth Engine* - Robert Brakenridge, University of Colorado Boulder
- *Prototyping Agile Production, Analytics and Visualization Pipelines for Big-Data on the NASA Earth Exchange (NEX)* - Aashish Chaudhary, Kitware, Inc.
- *Uncovering Effects of Climate Variables on Global Vegetation* - Kamalika Das, Universities Space Research Association
- *SpaceCubeX: A Hybrid Multi-core CPU/FPGA/DSP Flight Architecture for Next Generation Earth Science Missions* - Matthew French, USC Information Sciences Institute
- *Ontology-based Metadata Portal for Unified Semantics (OlyMPUS)* - Jonathan Gleason, NASA Langley Research Center
- *Computational Technologies: Feasibility Studies of Quantum Enabled Annealing Algorithms for Estimating Terrestrial Carbon Fluxes from OCO-2 and the LIS Model* - Milton Halem, University of Maryland, Baltimore County
- *Agile Big Data Analytics of High-Volume Geodetic Data Products for Improving Science and Hazard Response* - Hook Hua, Jet Propulsion Lab
- *OceanXtremes: Oceanographic Data-Intensive Anomaly Detection and Analysis Portal* - Thomas Huang, JPL
- *DERECHOS: Data Environment for Rapid Exploration and Characterization of Organized Systems* - Kwo-Sen Kuo, Bayesics, LLC
- *AMIGHO: Automated Metadata Ingest for GNSS Hydrology within OODT* - Kristine Larson, University of Colorado Boulder
- *Climate Model Diagnostic Analyzer (CMDA)* - Seungwon Lee, JPL
- *Tradespace Analysis Tool for Designing Earth Science Distributed Missions* - Jacqueline Le Moigne, NASA GSFC
- *Model Predictive Control Architecture for Optimizing Earth Science Data Collection* - Mike Lieber, Ball Aerospace & Technologies Corp
- *SciSpark: Highly Interactive and Scalable Model Evaluation and Climate Metrics for Scientific Data and Analysis* - Christian Mattmann, JPL
- *Land Information System for SMAP Tier-1 and AirMOSS Earth Venture-1 Decadal Survey Missions: Integration of SoilSCAPE, remote sensing, and modeling* - Mahta Moghaddam, University of Southern California
- *Computer-Aided Discovery of Earth Surface Deformation Phenomena* - Victor Pankratius, Massachusetts Institute of Technology
- *Illuminating the Darkness: Exploiting untapped data and information resources in Earth Science* - Rahul Ramachandran, NASA Marshall Space Flight Center
- *Empowering Data Management, Diagnosis, and Visualization of Cloud-Resolving Models by Cloud Library upon Spark and Hadoop* - Wei-Kuo Tao, NASA GSFC
- *A Service to Match Satellite and In-situ Marine Observations to Support Platform Intercomparisons, Cross-calibration, Validation, and Quality Control* - Shawn Smith, Florida State University
- *Pattern-based GIS for understanding content of very large Earth Science datasets* - Tomasz Stepinski, University of Cincinnati
- *Mining and Utilizing Dataset Relevancy from Oceanographic Dataset (MUDROD) Metadata, Usage Metrics, and User Feedback to Improve Data Discovery and Access* - Chaowei Yang, George Mason University

PROJECT SPOTLIGHT: SoilSCAPE

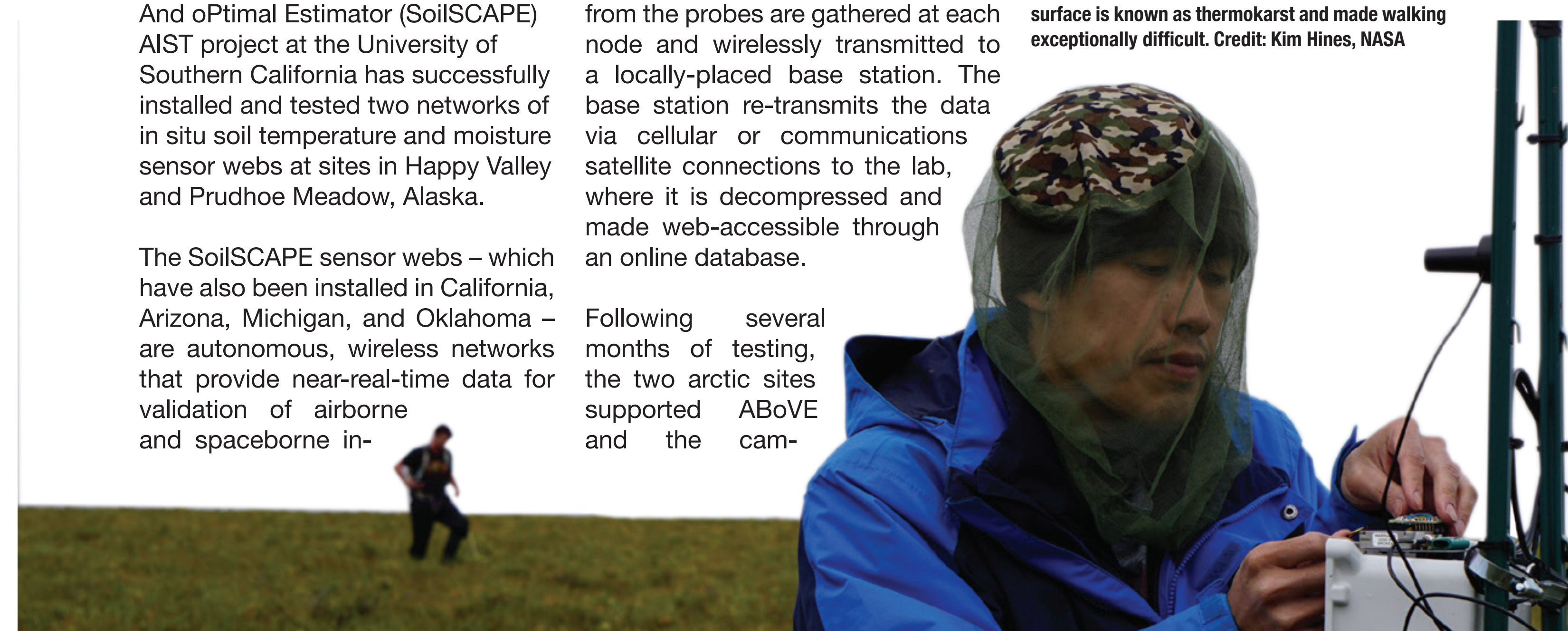
The Arctic Boreal Vulnerability Experiment (ABoVE), a far-reaching, 10-year, NASA-led field campaign that kicked off in 2016 to study environmental changes in the Arctic, got a new partner this year. The Soil moisture Sensing Controller And oPtimal Estimator (SoilSCAPE) AIST project at the University of Southern California has successfully installed and tested two networks of in situ soil temperature and moisture sensor webs at sites in Happy Valley and Prudhoe Meadow, Alaska.

The SoilSCAPE sensor webs – which have also been installed in California, Arizona, Michigan, and Oklahoma – are autonomous, wireless networks that provide near-real-time data for validation of airborne and spaceborne instruments, including for the NASA Soil Moisture Active and Passive (SMAP) mission.

Beginning in August 2016, several nodes of sensors were placed at the two Alaska sites. Each node contains soil probes at four depths below the tundra, from 5 cm below the surface to near the permafrost table. Data from the probes are gathered at each node and wirelessly transmitted to a locally-placed base station. The base station re-transmits the data via cellular or communications satellite connections to the lab, where it is decompressed and made web-accessible through an online database.

Following several months of testing, the two arctic sites supported ABoVE and the campaign's scientific research flights from April through September, providing in situ soil moisture and temperature data to compliment the airborne measurements. More information on SoilSCAPE, including access to SoilSCAPE data, is available online at: http://soilscape.usc.edu

BELOW: Richard Chen installs the SoilScape sensors at the Happy Vally field site. The spongy, uneven surface is known as thermokarst and made walking exceptionally difficult. Credit: Kim Hines, NASA



Technology Validation

NASA's vision for future Earth observations necessitates the development of emerging technologies capable of making new or improved Earth science measurements. Promising new capabilities, however, bring complexity and risk, and for some technologies there remains a critical need for validation in the hazardous environment of space.

ESTO's In-Space Validation of Earth Science Technologies (InVEST) program facilitates the space demonstration of technology projects that cannot be sufficiently evaluated on the ground or through airborne testing. Once validated in space, technologies are generally more adoptable, even beyond their intended use. To date, nine projects have been awarded through InVEST program solicitations. Two of those selections, the RAVAN and IceCube missions, launched in FY17 and continue to operate. Five other projects are slated to launch during FY18 (see pages 7-8).

PROJECT SPOTLIGHT: IceCube Deployed from International Space Station to Demonstrate New Way to Measure Cloud Ice

To better understand Earth's weather and changing climate, researchers need more information to reduce the uncertainty of clouds, specifically cloud ice, in these complex systems. While radiation and precipitation are being routinely observed at high and low altitudes, cloud ice measurements at altitudes between 5 and 15 km are limited. To demonstrate how new technologies could help fill this observation gap, ESTO funded the IceCube project with access to space enabled by NASA's CubeSat Launch Initiative.

Led by PI Dong Wu of NASA Goddard Space Flight Center, IceCube is flying an 883-GHz radiometer on a 3U CubeSat platform to test and validate a low-cost commercially available radiometer in the space environment. Submillimeter wave frequencies like what IceCube uses are unique for upper tropospheric cloud measurements and will yield new information not seen by microwave and infrared sensors. This type of technology could prove useful for future cloud and aerosol measurements, such as the planned Decadal Survey's ACE mission, or could be used on other upcoming NASA Earth observing missions.

Deployed from the International Space Station on May 16, 2017, IceCube has successfully completed the technology validation of the 883-GHz submillimeter wave radiometer portion of the mission. IceCube is continuing to collect data and is currently demonstrating the utility of submillimeter wave radiometry measurement to advance our understanding of cloud ice and its role in climate change.

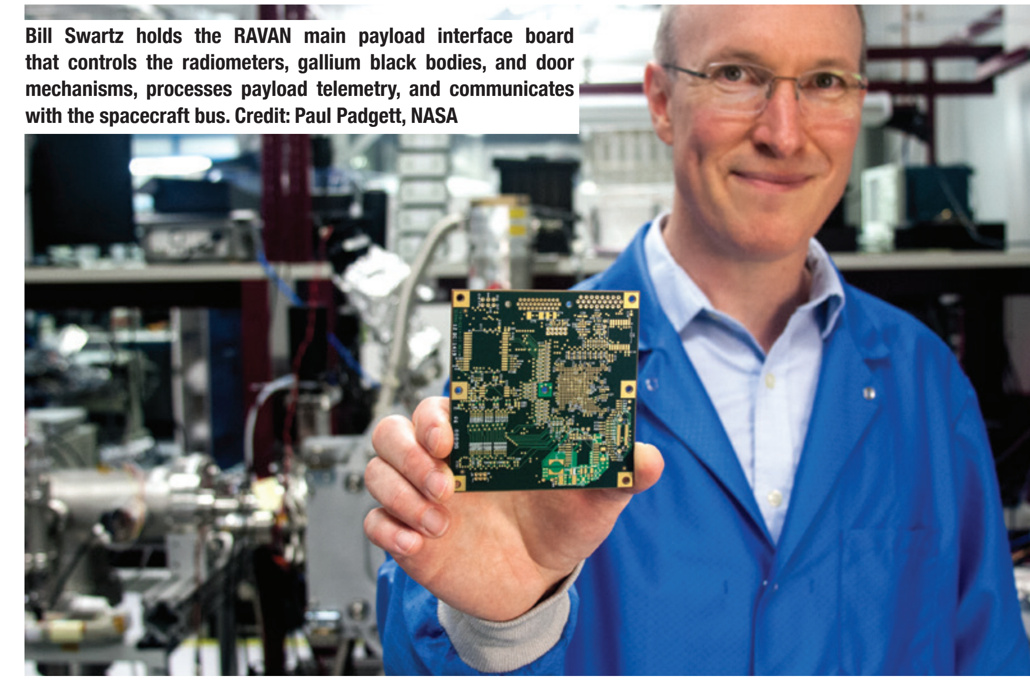
IceCube (rightmost CubeSat) as seen from the ISS shortly after a Nanoracks deployment on May 16, 2017. Credit: NASA

PROJECT SPOTLIGHT: RAVAN CubeSat Successfully Demonstrates Utility of New Technologies

Not long after the Radiometer Assessment using Vertically Aligned Nanotubes (RAVAN) CubeSat launched in November 2016, it began its mission of validating the use of carbon nanotube and gallium blackbody technologies to make improved measurements of Earth's radiation imbalance, a key factor in climate change.

The 3U CubeSat, developed by PI Bill Swartz of The Johns Hopkins University Applied Physics Laboratory, began taking Earth radiation data on January 25th, 2017 with small radiometers that utilize vertically aligned carbon nanotubes (VACNTs) as the instrument's light absorber. Because of the blackness of the nanotubes, the radiometer can gather the full spectrum of light reflected and emitted from the Earth to see even the smallest of changes in energy.

By August 9th, 2017, the project team had met all mission objectives and declared the use of the new technologies a success. Now, well-beyond the original six-month mission time frame, RAVAN continues to operate in low Earth orbit, collecting irradiance data that is helping the team refine and understand the payload performance. The success of the RAVAN mission could enable a constellation of RAVAN-like SmallSats for global coverage of Earth's radiation budget that could help researchers glean a better understanding of a changing climate.



Bill Swartz holds the RAVAN main payload interface board that controls the radiometers, gallium black bodies, and door mechanisms, processes payload telemetry, and communicates with the spacecraft bus. Credit: Paul Padgett, NASA

RAVAN Technology Given the Eclipse Test

While RAVAN's technology was developed to measure changes in Earth's outgoing energy, that same technology was used for a much different purpose on August 21, 2017.

The solar eclipse that captured the Nation's attention also gave researchers a unique opportunity to further test an important carbon nanotube attribute: its strong sensitivity to rapidly changing energy outputs. During the eclipse, RAVAN's highly sensitive nanotubes were trained not on the Earth, but on the sun to detect changes in the amount of incoming solar energy.

Because the researchers knew the CubeSat's location and the percentage of eclipse it would measure, it was easy for the team to compare the satellite's data to the known solar irradiance. Due to RAVAN's position in orbit, it did not catch eclipse totality. Instead, from its position high above the U.S., RAVAN collected data of an approximately 80 percent eclipse, similar as to what was observed from the Johns Hopkins Applied Physics Laboratory in Laurel, Maryland.

As the moon passed between Earth and the sun (shown here in the artist's depiction), RAVAN's instruments responded rapidly and accurately to measure the diminishing solar energy that was visible to the satellite's detectors. Swartz explained, "Although RAVAN routinely views the sun for solar calibration, it tracked the sudden change in solar energy afforded by the eclipse as expected."

Credit: Paul Padgett, NASA

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