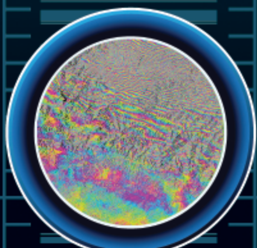
National Aeronautics and Space Administration



2015 Annual Report

NASA Earth Science Technology Office

Executive Summary

2015 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 this fiscal year ESTO funded 24 new projects under the Advanced Information Systems Technology (AIST) program and four new projects under the In-Space Validation of Earth Science Technologies (InVEST) program. The new AIST and InVEST awards can be found on pages 9 and 13, respectively.

ESTO continues to build upon a strong history of technology development and infusion. This year 40% of active ESTO technology projects advanced at least one Technology Readiness Level (TRL). Of the 690 completed projects in the ESTO portfolio, 31% have already been infused while an additional 48% 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 past and present principal investigators and their collaborators. We welcome the new group of AIST and InVEST investigators as they begin their selected projects and we look forward to their contributions that, along with our existing projects, will ensure a bright future for Earth science discovery.

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.

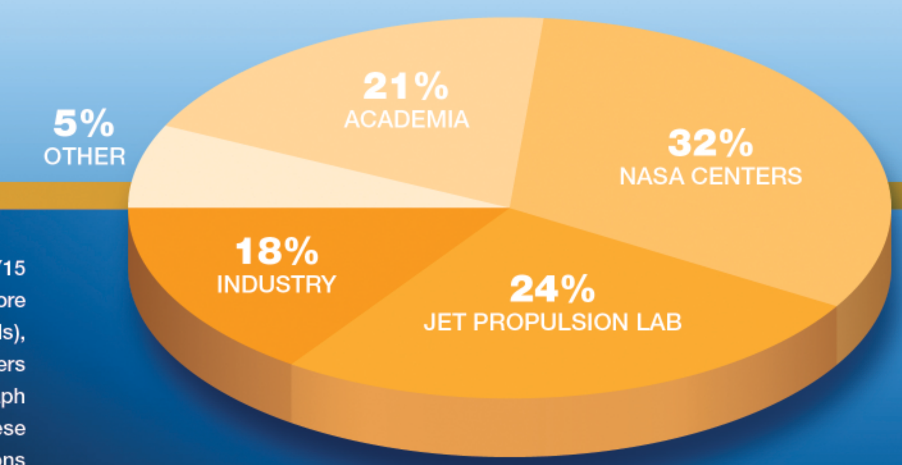
ESTO also applies a rigorous approach to technology development:

- 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 over 800 emerging technologies – 111 of which were active at some point during Fiscal Year 2015 (FY15) – 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 111 active projects during FY15 included the combined efforts of more than 385 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



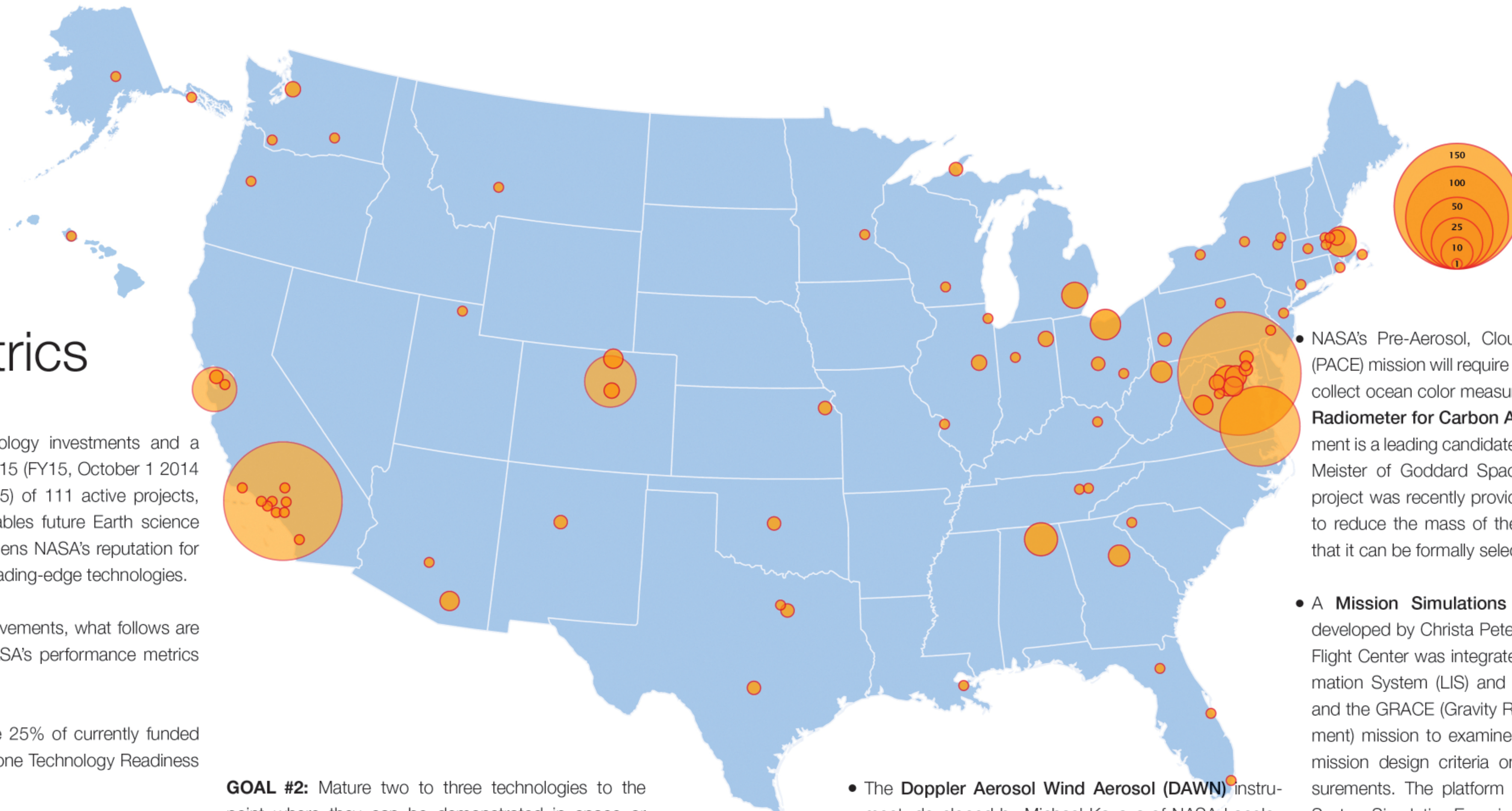
2015 Metrics

With 690 completed technology investments and a portfolio during fiscal year 2015 (FY15, October 1 2014 through September 30, 2015) of 111 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 FY15 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).

FY15 RESULT: 40% of ESTO technology projects funded during FY15 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.]

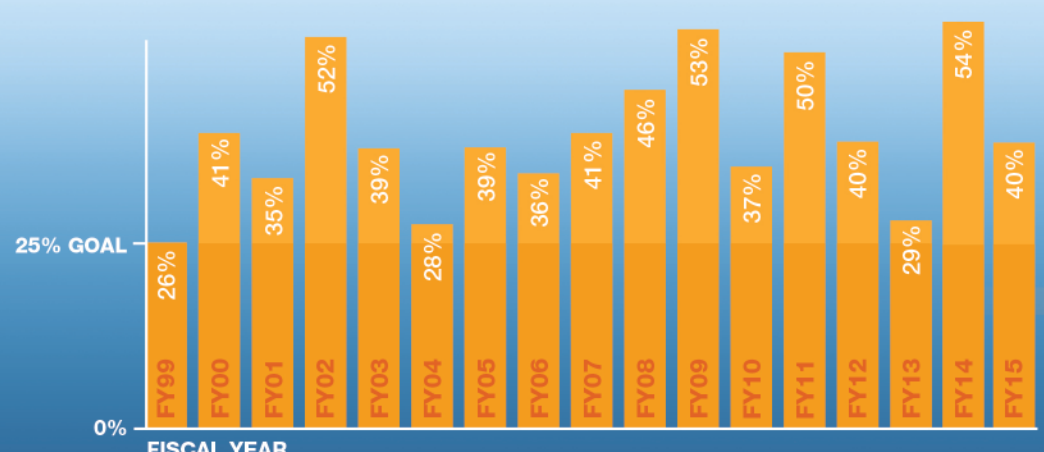


Map provides geographical distribution of principal investigators for the 801 projects (active and completed) in the ESTO portfolio.

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

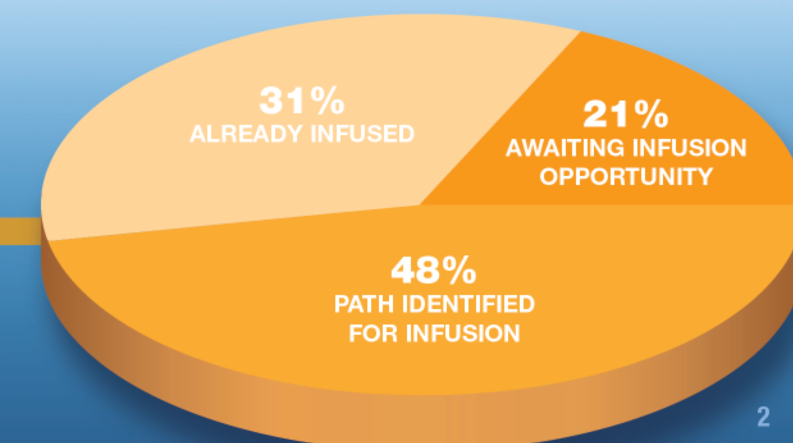
FY15 RESULT: At least nine ESTO projects achieved infusion into science measurements, airborne campaigns, data systems, or follow-on development activities in FY15. Examples include:

- The **Doppler Aerosol Wind Aerosol (DAWN)** instrument, developed by Michael Kavaya of NASA Langley Research Center, was flown on the UC-12B aircraft as part of NASA's Polar Winds project to demonstrate polar ice loss measurement science capabilities and provide cal/val for ESA's upcoming Atmospheric Dynamics Mission (ADM) orbiting wind lidar space mission. The flights over Greenland took place 10/20 - 11/14/2014.
- NASA's Pre-Aerosol, Clouds, and ocean Ecosystem (PACE) mission will require an ocean color radiometer to collect ocean color measurements globally. The **Ocean Radiometer for Carbon Assessment**, or ORCA, instrument is a leading candidate for this role. Led by Gerhard Meister of Goddard Space Flight Center, the ORCA project was recently provided additional NASA funding to reduce the mass of the flight version of ORCA, so that it can be formally selected by the PACE mission.
- A **Mission Simulations and Evaluation Platform** developed by Christa Peters-Lidard of Goddard Space Flight Center was integrated into the NASA Land Information System (LIS) and used by scientists from LIS and the GRACE (Gravity Recovery and Climate Experiment) mission to examine the impact of future gravity mission design criteria on terrestrial hydrology measurements. The platform was used as an Observing System Simulation Experiment, or OSSE, to quantify the scienttific impact of various mission scenarios involving one pair and two pairs of laser-ranging satellites as well as single- and two-satellite configurations using Cold Atom Gravity Gradiometer technology. The conclusions from this study are expected to contribute to the GRACE-2 mission configuration.



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

ESTO's infusion success—drawn from the 690 completed projects through the end of FY15



2015 Metrics (continued)

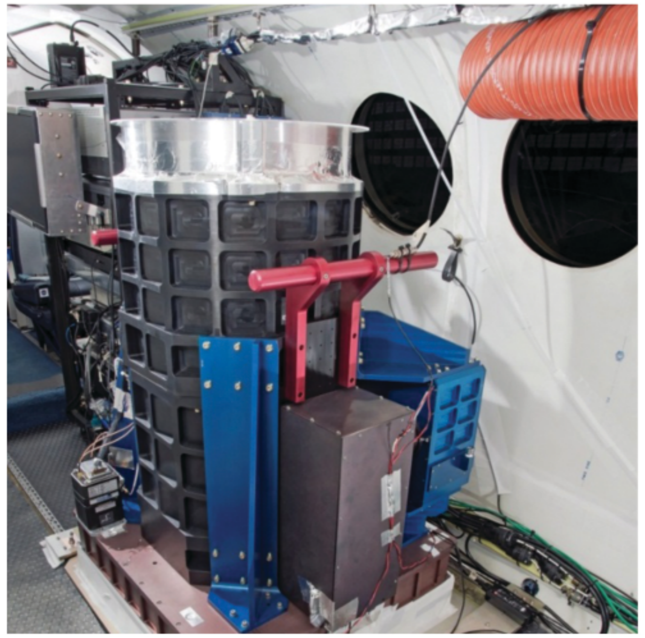
GOAL #3: Enable a new science measurement or significantly improve the performance of an existing technique.

FY15 RESULT: One notable example:
Over 11 days in late March, the pulsed 2 micron direct detection IPDA (Integrated Path Differential Absorption) Lidar completed 10 engineering flights, totalling about 27 hours, over Virginia onboard the NASA B200 King Air aircraft. The compact lidar aims to provide accurate, high-resolution atmospheric CO_2 column measurements. Results from the tests are positive and the instrument has likely performed the first proof-of-principle demonstration of an airborne, direct-detection, 2 micron CO_2 measurement.

Nearly two decades of investment in DIAL systems and 2 micron transmitters has resulted in high-energy, double-pulse lasers with high repetition rates. The laser pulses can be tuned and locked near the 2.05 micron wavelength, an ideal spectral region for CO_2 sensing. Separated by 150 microseconds, the first pulse is tuned to a high CO_2 absorption wavelength and the second pulse to a low absorption wavelength. By aiming the pulses at a hard target, or Earth, the difference between the return signals correlates to the average amount of CO_2 in the column between the instrument and the target.

The test flights occurred over diverse terrain with varying reflectivity, and analysis shows the measured optical depth for column length matched the modeled value within a few percent.

The instrument is intended to be a stepping-stone toward an eventual space-borne mission for active remote sensing of CO_2, such as the ASCENDS (Active Sensing



Top: The 2 micron IPDA lidar system installed in the NASA B200. **Bottom:** The project team pauses for a photo during test flights. (Image credit: Upendra Singh)

of CO_2 Emissions over Nights, Days, and Seasons) mission concept. The project team, led by Upendra Singh at Langley Research Center, is working to incorporate a third transmitted pulse. A triple-pulsed system would enable simultaneous CO_2 and water vapor (H_2O) measurements in a single compact instrument.

Student Participation

Student participation in ESTO projects has always been substantial. Since 1998, nearly 650 students from over 210 institutions have been involved in ESTO-funded work and at least 148 graduate-level degrees have been awarded. In 2015 alone, 175 students were actively involved with ESTO projects. Roughly half are pursuing doctorates while the remainder are working toward master or undergraduate degrees.

An information systems project led by Chris Mattmann of the Jet Propulsion Lab developed methods to improve interactivity and data ingestion for the Regional Climate Model Evaluation System (RCMES), a system that facilitates regional-scale evaluations of climate and Earth system models by providing standardized access to a comprehensive set of data, models, and analysis tools. Dr. Paul Loikith, **at left**, a CalTech Postdoctoral Fellow, worked on methodologies for evaluating temperature distributions, extremes, and associated mechanisms in regional climate models using high-resolution reanalysis. Paul has a Ph.D. in atmospheric science from Rutgers University. (Credit: P. Loikith)

The GEO-CAPE ROIC In-Flight Performance Experiment (GRIFEX) is a 3U CubeSat built by the University of Michigan's Michigan Exploration Laboratory (MXL) to perform an engineering assessment of an all digital in-pixel high frame rate Read-Out Integrated Circuit (ROIC) developed by the Jet Propulsion Lab (see page 14). **Pictured at left** are three of the master's students that worked on the project, from left to right: Tyler Rose, an Electrical Engineering major and the MXL GRIFEX project manager; So-Hee Kang. an Aerospace Engineering major and the project's chief engineer; and Charles Lacy, an Electrical Engineering major and the operations lead. (Credit: Kaitlyn Burke, University of Michigan)

Venturing Forth

ESTO Technology Infusions in Earth Venture

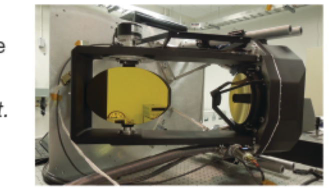
NASA Earth Venture, managed by the Earth System Science Pathfinder Program (ESSP), consists of a series of new science-driven missions and airborne campaigns that provide opportunities for investment in innovative Earth science measurements. Intended to enhance our capability to understand the Earth system and to enable the prediction of future changes, Earth Venture was established to fund, through a series of frequent open solicitations, innovative research missions that might address any area of Earth science, including the atmosphere, oceans, land surface, polar ice regions, and solid earth. "Venture-class" missions are of low-to-moderate cost, small to medium-sized, and competitively selected. There are currently three categories of Earth Venture missions: 1) Full orbital missions, or Earth Venture Missions (EVM); 2) Suborbital missions and campaigns, or Earth Venture Suborbital (EVS), that utilize aircraft, balloons, sounding rockets, and other suborbital assets; and 3) Instruments that require final development for future use in orbit, known as Earth Venture Instruments (EVI). From the beginning of the Earth Venture program in 2010, ESTO technologies have played key roles in nearly every selection. The following timeline depicts ESTO technology infusions into these critical missions.

Earth Venture Instrument-2

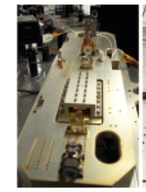
ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) - Instrument Delivery 2019

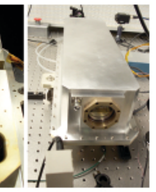
PI: Simon Hook, Jet Propulsion Laboratory (JPL)

From the International Space Station, ECOSTRESS will use a high-resolution thermal infrared radiometer to measure plant evapotranspiration, and reveal how ecosystems change with climate. The ECOSTRESS instrument is a direct descendant of the **Prototype Thermal Infrared Radiometer for Earth Science (PHyTIR - Simon Hook, JPL)**, *right*.



Global Ecosystem Dynamics Investigation Lidar (GEDI) - Instrument Delivery 2019





PI: Ralph Dubayah, University of Maryland

Focused on tropical and temperate forests from the vantage point of the International Space Station, GEDI will use lidar to provide the first global, high-resolution observations of forest vertical structure. GEDI benefits from several ESTO Laser Risk Reduction Program (LRRP), particularly the work that led to the **High Output Maximum Efficiency Resonator (HOMER) Laser (Barry Coyle, GSFC)**, *shown at left*,which will be used for the GEDI instrument.

Selection announcements for Earth Venture Mission-2 and Earth Venture Instrument-3 are anticipated in 2016

2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017

Earth Venture Suborbital-1 (2010-2015)

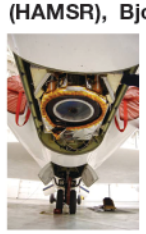
Three of Five Selected Missions Included ESTO Technology:

Hurricane and Severe Storm Sentinel (HS3)

Principal Investigator (PI): Scott Braun, Goddard Space Flight Center (GSFC)

HS3 was a five-year airborne mission targeted at understanding the processes that underlie hurricane intensity change in the Atlantic Ocean. Four of the seven instruments carried by the two Global Hawk UAVs for HS3 have ESTO heritage:

- **High Altitude Monolithic Microwave integrated Circuit (MMIC) Sounding Radiometer (HAMSR), Bjorn Lambrigtsen, Jet Propulsion Laboratory (JPL)**



- **High Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP), Gerry Heymsfield, GSFC**
- **Tropospheric Wind Lidar (TWiLiTE),** *at left*, **Bruce Gentry, GSFC**
- **An Agile Digital Detector (ADD) for radio frequency interference mitigation used by the Hurricane Imaging Radiometer (HIRAD) instrument, Chris Ruf, University of Michigan**

DISCOVER-AQ

PI: James Crawford, Langley Research Center (LaRC) - The Deriving Information on Surface Conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ) airborne campaign aimed to improve the interpretation of satellite observations to diagnose near-surface conditions relating to air quality. In 2013, the **Geostationary Trace gas and Aerosol Sensor Optimization (GEO-TASO - James Leitch, Ball Aerospace)** instrument *(at left)* joined the campaign to provide aerosol and trace gas measurements.

Airborne Microwave Observatory of Subcanopy and Subsurface (AirMOSS)

PI: Mahta Moghaddam, University of Southern CA - The AirMOSS campaign utilized the **Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR - Scott Hensley / Yunling Lou, JPL)** instrument, *shown below on the NASA Gulfstream III aircraft*, to provide high-resolution observations of root-zone soil moisture over regions of North America.

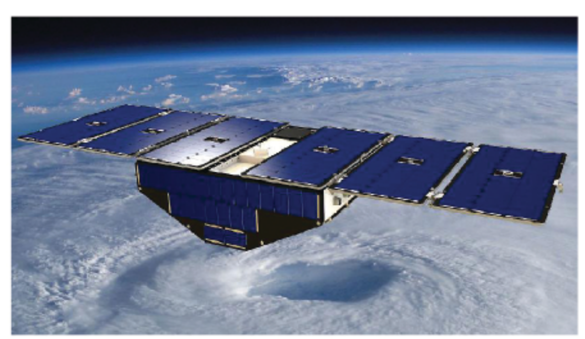
Earth Venture Mission-1

Launch 2016

Cyclone Global Navigation Satellite System (CYGNSS)

PI: Chris Ruf, University of Michigan

The Cyclone Global Navigation Satellite System (CYGNSS) consists of eight micro-satellite observatories (*shown above and below*) that will make frequent and accurate measurements of ocean surface winds throughout the life cycle of tropical storms and hurricanes. The satellites will receive both direct and reflected signals from Global Positioning System (GPS) satellites; the direct signals pinpoint CYGNSS observatory positions, while the reflected signals will respond to ocean surface roughness, from which wind speed is retrieved. The mission concept finds significant heritage in an airborne **GPS Reflection Wind Speed System (Stephen Katzberg, LaRC, and a CYGNSS Co-Investigator)** that was demonstrated onboard a NOAA aircraft in 2004 to estimate ocean surface wind speeds.



Earth Venture Instrument-1

Instrument Delivery 2017

Tropospheric Emissions: Monitoring of Pollution (TEMPO)

PI: Kelly Chance, Smithsonian Astrophysical Observatory, Cambridge, MA

TEMPO, a UV-Vis spectrometer, will provide data on major pollutants in the troposphere. Two ESTO instruments continue to play a pivotal role in the development and operation of TEMPO: The **Geostationary spectrograph for Earth and Atmospheric Science Applications (GeoSpec - Scott Janz, GSFC)**, *shown below,* and the **Geostationary Trace Gas and Aerosol Sensor Optimization (GeoTASO - James Leitch, Ball Aerospace)**. GeoSpec development is helping refine the sensor concept necessary for TEMPO, and the GeoTASO algorithm design is guiding TEMPO algorithm requirements. The GeoTASO instrument will also be used as an airborne validation tool for the TEMPO mission.

Earth Venture Suborbital-2 (2015-2020)

Five of Six Selected Missions Include ESTO Technology:

North Atlantic Aerosols and Marine Ecosystems Study (NAAMES)

PI: Michael Behrenfeld, Oregon State University - NAAMES seeks to improve our understanding of how ocean ecosystems might change with ocean warming. NAAMES utilizes the **High Spectral Resolution Lidar (HSRL - Johnathan Hair / Chris Hostetler, LaRC)** instrument *(shown onboard the UC-12 aircraft)* to measure the vertical distribution of aerosols within the atmosphere and phytoplankton to three optical depths (~45 m) in the ocean.

Atmospheric Transport and Carbon-America (ACT-America)

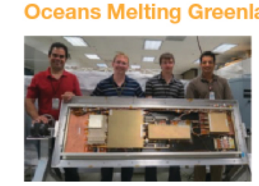
PI: Kenneth Davis, Pennsylvania State University - ACT-America is also using the HSRL instrument above as well as the **Multi-Functional Fiber Laser Lidar (MFLL - Michael Dobbs, ITT Excelis)** *at left* to quantify the sources of regional carbon dioxide, methane and other gases, as well as document how weather systems transport these gases in the atmosphere.

ObseRvations of Aerosols above CLouds and their interactions (ORACLES)

PI: Jens Redemann, Ames Research Center - the ORACLES campaign, which is investigating how biomass burning in Africa influences cloud cover over the Atlantic, includes the **Airborne Second Generation Precipitation Radar (APR-2 - Eastwood Im / Steve Durden, JPL)** instrument *(Steve Durden with the APR-2 at left)* and the **Airborne Multiangle SpectroPolarimetric Imager (AirMSPI - David Diner, JPL).**

Oceans Melting Greenland (OMG)

PI: Josh Willis, JPL - The OMG campaign will utilize the **Airborne Glacier and Land Ice Surface Topography Interferometer (GLISTIN-A - Delwyn Moller, Remote Sensing Solutions)** instrument to investigate the role of warmer, saltier Atlantic subsurface waters in Greenland glacier melting. *(At left: GLISTIN team members with an antenna panel).*



COral Reef Airborne Laboratory (CORAL)

PI: Eric Hochberg, Bermuda Institute of Ocean Science - The CORAL campaign aims to provide critical data and new models to analyze the status of coral reefs and to predict future changes. CORAL is using the **Portable Remote Imaging SpectroMeter (PRISM - Pantazis Mouroulis, JPL)** instrument *(shown at left)* to acquire spectral image data related to reef health.

Earth Venture Suborbital | Earth Venture Mission | Earth Venture Instrument

2015 in Review: Instruments

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

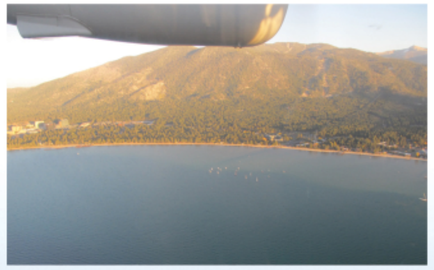
The IIP included 30 active projects in FY15, seven of which completed over the course of the year. These FY15 graduates are as follows:

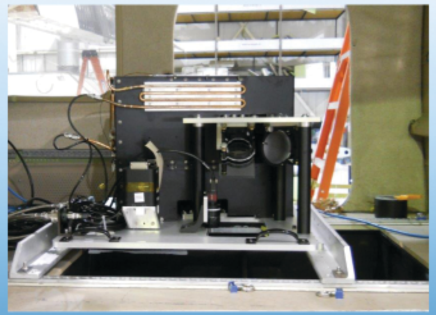
- *Atomic Gravity Gradiometer for Earth Gravity Mapping and Monitoring Measurements* - Nan Yu, Jet Propulsion Laboratory (JPL)
- *HyperSpectral Imager for Climate Science (HySICS)* - Greg Kopp, University of Colorado/LASP
- *Antenna Technologies for 3D Imaging, Wide Swath Radar Supporting ACE* - Paul Racette, Goddard Space Flight Center (GSFC)
- *ASCENDS Lidar: Acceleration and demonstrations of key space Lidar technologies* - James Abshire, GSFC
- *Development of an Internally-Calibrated Wide-Band Airborne Microwave Radiometer to Provide High-Resolution Wet-Tropospheric Path Delay Measurements for SWOT (HAMMR, the High-frequency Airborne Microwave and Millimeter-wave Radiometer)* - Steven Reising, Colorado State University
- *EcoSAR: The first P-band Digital Beamforming Polarimetric Interferometric SAR instrument to measure Ecosystem Structure, Biomass and Water* - Temilola Fatoyinbo, GSFC
- *ASCENDS CarbonHawk Experiment Simulator (ACES)* - Michael Obland, Langley Research Center

All seven advanced at least one TRL during the funding period. The next IIP solicitation release is anticipated in 2016.

SPOTLIGHT:

Test Flights Demonstrate Coastal Imaging Instrument





Top: An airborne view of Lake Tahoe during the October 11, 2014, test flight.
Bottom: The MOS instrument installed in the Twin Otter aircraft.
(Credit: Tim Valle, Ball Aerospace)

The Multi-Slit Optimized Spectrometer (MOS) prototype instrument conducted a series of engineering flight tests in October 2014 onboard a Twin Otter aircraft to demonstrate and validate the multi-slit concept for hyperspectral ocean color retrievals with real world scenes. MOS, a 2010 IIP project, was designed and developed to provide a small coastal imaging spectrometer that would meet the projected measurement requirements of the GEOstationary Coastal and Air Pollution Events (GEO-CAPE) mission concept.

The instrument design represents a new option for hyperspectral sensing: MOS multiplexes a scene by imaging from multiple slits at the same time, acting like four separate imagers. The technology could dramatically reduce payload size and mission risk for a geostationary mission. The flights, totaling up to 26 hours, were conducted over Lake Tahoe and the Sacramento and San Joaquin rivers and included some over-flights of *in situ* (boat-based) water quality measurements.

Work on MOS completed in August 2015 following extensive data analysis. Looking forward, the project team – led by Tim Valle of Ball Aerospace – hopes to add a polarimeter in order to demonstrate simultaneous characterization of aerosols above coastal scenes.

SPOTLIGHT:

Successful First Flights of Wideband Instrument for Snow Measurements

Seasonal snowpack supplies 50% to 80% of the yearly water supply in the Western United States. To effectively manage water resources, frequent and accurate measurements of the amount of water in the snowpack – the snow water equivalent – are critical to understand the very small spatial scales over which the snowpack varies.

In late February 2015, the Wideband (8-40 GHz) Instrument for Snow Measurement (WISM) was installed on a Twin Otter aircraft for a series of demonstration flights over snow covered areas of Colorado. WISM, an IIP project selected in 2013, is an airborne instrument comprised of a dual-frequency (X- and Ku-bands) Synthetic Aperture Radar (SAR) and a dual-frequency (K- and Ka-bands) radiometer. The radar frequencies are 9.6 and 17.2 GHz, while the fixed-beam radiometer operates at 18.7 and 36.5 GHz. The instrument also utilizes a broadband current sheet array (CSA) antenna feed that enables the integration of the radar and radiometer using a single antenna aperture.

In 9.4 hours of total flight time, the WISM team, led by Tim Durham of Harris Corporation, collected high-resolution snow data over a broad range of snowpack conditions near Grand Junction, CO, particularly over an experiment site on Grand Mesa. To validate the WISM retrievals, extensive *in situ* snow-pack profiles were taken using high-resolution ground based radar as well as ancillary airborne lidar measurements. The instrument demonstrated the wideband antenna performance a well as near-simultaneous sensing with both the radar and radiometer.

Right: The WISM instrument being integrated into the Twin Otter Aircraft. **Below Right:** The Twin Otter gets a final checkout on the first day of flights. **Below:** The ground crew takes a break. Ground observations were carried out on Grand Mesa along the WISM flight line and included 19 detailed snow pits (snow density, temperature, grain size, grain type, layer thickness profiles), 8,000+ manual depth measurements, and two snowmobile-based radars that profiled the entire line multiple times at 10 cm resolution. (Credit: Tim Durham, Harris Corp.)

2015 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.

The AIST program included 43 active investments in FY15, 24 of which were added in December 2014 through a competitive solicitation. These new awards are as follows:

- *Global Flood Risk from Advanced Modeling and Remote Sensing in Collaboration with Google Earth Engine* - Robert Brakenridge, University Of Colorado, Boulder
- *UAV Based Spectral Systems for Environmental Monitoring* - Petya Campbell, Goddard Space Flight Center (GSFC)
- *Prototyping Agile Production, Analytics and Visualization Pipelines for big-data on the NASA Earth Exchange (NEX)* - Aashish Chaudhary, Kitware, Inc.
- *Development of Computational Infrastructure to Support Hyper-Resolution Large-Ensemble Hydrology Simulations from Local to Continental Scales* - Martyn Clark, National Center for Atmospheric Research
- *DERECHOS: Data Environment for Rapid Exploration and Characterization of Organized Systems* - Thomas Clune, GSFC
- *Uncovering Effects of Climate Variables on Global Vegetation* - Kamalika Das, Ames Research Center
- *SpaceCubeX: A Hybrid Multi-core CPU/FPGA/DSP Flight Architecture for Next Generation Earth Science Missions* - Matthew French, University of Southern California Information Sciences Institute
- *Ontology-based Metadata Portal for Unified Semantics (OlyMPUS)* - Jonathan Gleason, Langley Research Center (LaRC)
- *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 Laboratory (JPL)
- *OceanXtremes: Oceanographic Data-Intensive Anomaly Detection and Analysis Portal* - Thomas Huang, JPL
- *Multi-channel Combining for Airborne Flight Research using Standard Protocols* - William Ivancic, Glenn Research Center
- *AMIGHO: Automated Metadata Ingest for GNSS Hydrology within OODT* - Kristine Larson, University of Colorado
- *Climate Model Diagnostic Analyzer* - Seungwon Lee, JPL
- *Tradespace Analysis Tool for Designing Earth Science Distributed Missions* - Jacqueline LeMoigne, GSFC
- *Model Predictive Control Architecture for Optimizing Earth Science Data Collection* - Mike Lieber, Ball Aerospace
- *NASA Information and Data System (NAIADS) for Earth Science Data Fusion and Analytics* - Constantine Lukashin, LaRC
- *SciSpark: Highly Interactive and Scalable Model Evaluation and Climate Metrics for Scientific Data and Analysis* - Christian Mattmann, JPL
- *Computer-Aided Discovery of Earth Surface Deformation Phenomena* - Victor Pankratius, M.I.T.
- *Illuminating the Darkness: Exploiting untapped data and information resources in Earth Science* - Rahul Ramachandran, Marshall Space Flight Center
- *A Service to Match Satellite and In-situ Marine Observations to Support Platform Inter-comparisons, 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
- *Empowering Data Management Diagnosis, and Visualization of Cloud-Resolving Models by Cloud Library upon Spark and Hadoop* - Wei-Kuo Tao, GSFC
- *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

Nine AIST projects completed this year, all of which advanced at least two TRLs over their course of funding. These FY15 graduates are as follows:

- *High-Speed On-Board Data Processing for Science Instruments (HOPS)* - Jeffrey Beyon, LaRC
- *Empowering Cloud Resolving Models Through GPU and Asynchronous IO* - Wei-Kuo Tao, GSFC
- *Integration of the NASA CAMVis and Multiscale Analysis Package (CAMVis-MAP) For Tropical Cyclone Climate Study* - Bo-Wen Shen, San Diego State University
- *QuakeSim: Multi-Source Synergistic Data Intensive Computing for Earth Science* - Andrea Donnellan, JPL
- *On-Board Processing (OBP) to Advance the PanFTS Imaging System for GEO-CAPE* - Jean-Francois Blavier, JPL
- *EPOS for Coordination of Asynchronous Sensor Webs* - Stephan Kolitz, C. S. Draper Laboratory
- *Plume Tracker: Interactive Mapping of Atmospheric Plumes via Volumetric Ray Casting* - Alexander Berk, Spectral Sciences, Inc.
- *High Performance, Onboard Multicore Intelligent Payload Module for Orbital / Suborbital Remote Sensing Missions* - Daniel Mandl, GSFC
- *Semi-Automatic Science Workflow Synthesis for High-End Computing on the NASA Earth Exchange* - Ramakrishna Nemani, ARC

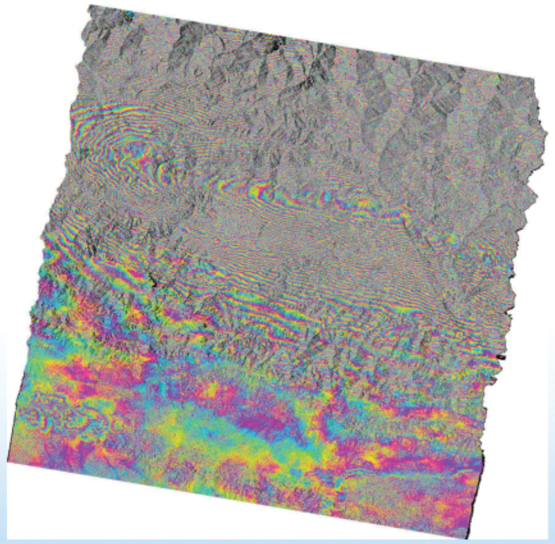
SPOTLIGHT:

New System Put Into Service to Process Nepal Earthquake Data

During the initial response to the April 25 Gorkha Earthquake in Nepal, data processing was done by hand as it was obtained and assembled, and interferograms were processed one at a time.

Within the first week, the Advanced Rapid Imaging and Analysis (ARIA) Center at JPL/Caltech automated and customized many aspects of the process to increase efficiency. To achieve this improvement, the ARIA center utilized parts of an AIST 2011 project, ARIA for Monitoring Hazards (ARIA-MH) led by Hook Hua of JPL. Hua is working to developing a service-oriented hazard and disaster data system to monitor ground motion with GPS and Interferometric synthetic aperture radar (InSAR) data.

Although not fully operational, ARIA-MH was leveraged to help rapidly process and re-process interferograms from the Sentinel-1A satellite InSAR data in a highly-parallel cloud computing environment. The automation and scaled-up processing significantly sped up the turnaround time, enabling scientists to quickly assess new data from Nepal and reprocess the scenes with additional customizations and tweaks.



This interferogram shows part of the very large deformation caused by the 2015 magnitude 7.8 earthquake in Nepal, including the capital city of Kathmandu. The color contours or fringes are 2.8 cm (1.1 inches) each and reflect the surface deformation caused by fault slip at depths of 12-16 km depth. The area just north of Katmandu moved upward about 1.4 m due to the earthquake. (Credit: Hook Hua, JPL)

2015 in Review: Components

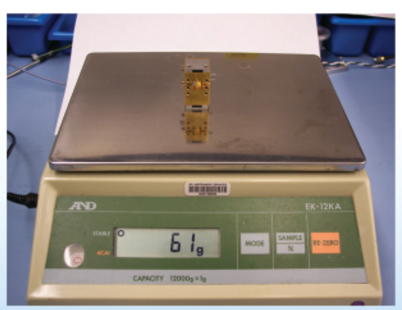
The Advanced Component Technology (ACT) program leads research, development, testing, and demonstration of component- and subsystem-level technologies for use in state-of-the-art Earth science instruments and information systems. The ACT program funding is primarily geared toward producing technologies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

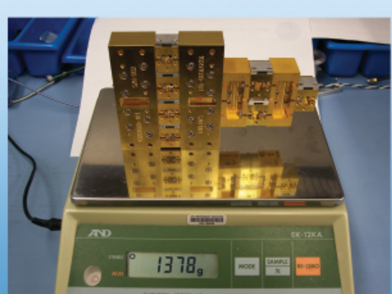
The ACT program aims to mature component technologies to a level that allows further development by other NASA programs or their integration into other technology projects, such as those selected by the Instrument Incubator Program. In other cases, the ACT program produces component technologies of sufficient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

In FY15, the ACT program portfolio held 23 investments, six of which were completed this year:

- *A Compact Remote Sensing Lidar for High Resolution Measurements of Methane* - Haris Riris, Goddard Space Flight Center (GSFC)
- *HgCdTe Infrared Avalanche Photodiode Single Photon Detector Arrays for the LIST and Other Decadal Missions* - Xiaoli Sun, GSFC
- *Advanced Amplifier Based Receiver Front Ends for Submillimeter-Wave Sounders* - Goutam Chattopadhyay, Jet Propulsion Laboratory (JPL)
- *High Efficiency, Digitally Calibrated TR Modules Enabling Lightweight SweepSAR Architectures for NASA-ISRO SAR (NISAR)-class Radar Instruments* - James Hoffman, JPL
- *Combined HSRL and Optical Autocovarience Wind Lidar (HOAWL) Demonstration* - Thomas Delker, Ball Aerospace & Technologies Corp.
- *High Power Mid-IR Laser Development 2.8 to 3.5 Microns* - James Anderson, Harvard University

All of these completed ACT projects advanced at least one TRL during their course of funding. The next ACT solicitation is anticipated in 2016/2017.





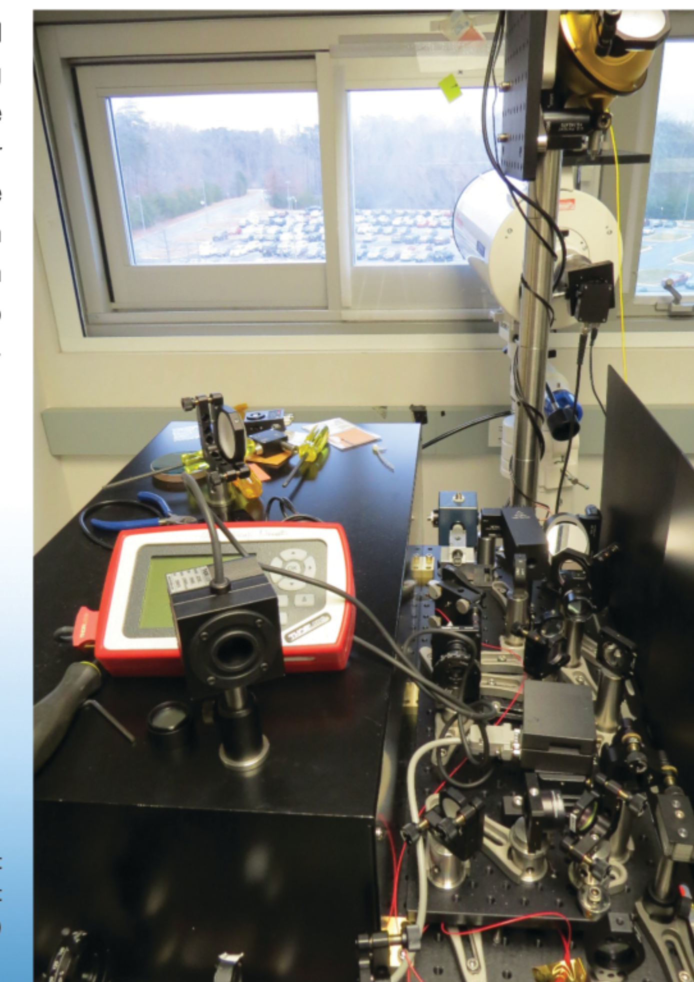
A 2010 ACT project has fabricated W-Band (75-110 GHz) Gallium Nitride (GaN) Monolithic Microwave Integrated Circuit (MMIC) amplifiers that show promise for future cloud Doppler radar applications. The MMICs – including power amplifiers, low noise amplifiers, and driver amplifiers – are major components of a scanning antenna feed array for a 94 GHz Doppler radar. This type of radar is proposed for the NASA Aerosols/Clouds/Ecosystems (ACE) mission concept and could provide wide-swath profiling measurements of atmospheric clouds and precipitation. GaN amplifiers, such as the **GaN driver amplifier top left**, are presently the highest power density semiconductor transistor amplifier technology that can function in W-band. The improvement in efficiency over other W-band technology, such as the **Gallium Arsenide driver amplifier bottom left**, will allow reductions in size, weight, power consumption and heat dissipation, which are all beneficial for space instrument operations. (Credit: Andy Fung, JPL/Caltech)

SPOTLIGHT:

A Compact Remote Sensing Lidar for High-Resolution Methane Measurements

In April 2015, a 2010 ACT task wrapped up development of a laser transmitter for active remote sensing of atmospheric methane (CH4), a strong greenhouse gas. An active-sensing laser instrument in low Earth orbit could someday enable day and night measurements of CH4 at all latitudes, including through optically thin clouds. The work focused on integrating a relatively new, high-power, Ytterbium-doped pulsed fiber laser, developed by Fibertek, as the 1 micron pump source for the optical parametric amplifier (OPA). An all-fiber laser system has fewer optical interfaces, reducing the risk for misalignment, damage, or contamination. The system achieved a 2-times improvement in power, to approximately 200 μJ, from prior capabilities. The system also completed a 65-hour open path test, measuring the CH4 column to a 1.5 km target, that showed good agreement to a trace gas analyzer.

The project team, led by Haris Riris of the Goddard Space Flight Center, was awarded new funding under the 2013 ACT competitive solicitation. The focus of this new effort will be to scale the laser transmitter energy up to 300 μJ, demonstrate methane column abundance measurements with 1% precision, and package the transmitter for an airborne demonstration. The team also proposes to extend the wavelength coverage to provide simultaneous measurements of atmospheric water vapor, another strong greenhouse gas.



Right: The 1.5 km open path test setup at Goddard Space Flight Center. (Credit: Haris Riris, GSFC)

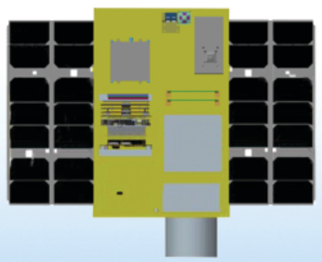
2015 in Review: Space Validation

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. The first InVEST solicitation was released in 2012 and five projects, from 24 proposals total, were awarded in 2013. These projects are making good progress and are expected to launch beginning in 2016.

A second InVEST solicitation was released in February 2015. Four out of a total of 23 received proposals were selected in September. All will use the 6U CubeSat platform.* The 2015 awards are as follows:

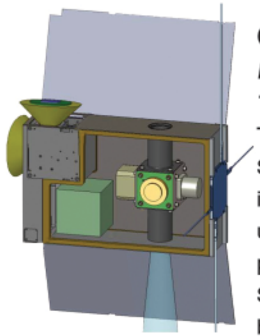
CubeRTT



Joel Johnson, Ohio State University

The CubeSat Radiometer Radio Frequency Interference (RFI) Technology Validation (CubeRTT) mission will demonstrate wideband RFI mitigating backend technologies vital for future space-borne microwave radiometers. Man-made RFI hampers geophysical retrievals in a variety of crucial science products, including soil moisture, atmospheric water vapor, sea surface temperature, sea surface winds, and many others. This technology will allow new measurements to operate in previously unusable spectral regions and over larger bandwidths.

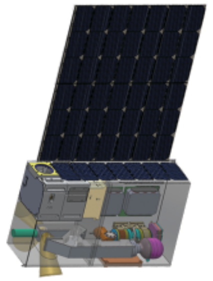
CIRiS



David Osterman, Ball Aerospace & Technologies Corporation

The Compact Infrared Radiometer in Space (CIRiS) is an uncooled imaging infrared radiometer (7.5 um to 13 um) designed for high radiometric performance from LEO on a CubeSat spacecraft. A high-emissivity blackbody source coated with carbon nanotubes reduces error in on-board calibration, and algorithms compensate the detector signal for changing external temperatures. The CIRiS mission could enable constellations of simple, inexpensive CubeSats to replace larger more complex instruments for multiple applications in scientific research and land use management.

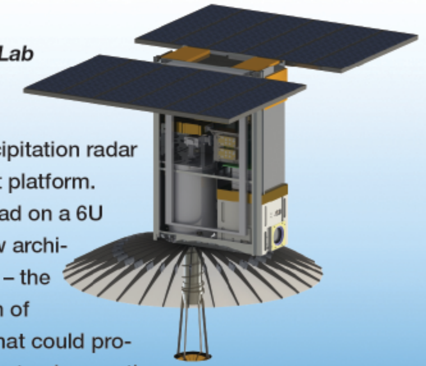
CIRAS



Thomas Pagano, Jet Propulsion Lab

The CubeSat Infrared Atmospheric Sounder (CIRAS), which consists of an infrared grating spectromter (in the 4-5 micron spectral region) with infrared detectors and micro-cryocooler, is intended to demonstrate an instrument system capable of temperature and water vapor measurements in the lower troposphere. A high-emissivity blackbody source coated with carbon nanotubes reduces error in on-board calibration. CIRAS could enable constellations of atmospheric sounders for improved latency and data continuity.

RainCube



Eva Peral, Jet Propulsion Lab

The Radar in a CubeSat (RainCube) project will demonstrate Ka-band precipitation radar technologies on a low-cost platform. The 35.75 GHz radar payload on a 6U CubeSat will validate a new architecture for Ka-band radars – the potential for a constellation of precipitation instruments that could provide the temporal resolution to observe the evolution of weather – as well as an ultra-compact deployable Ka-band antenna technology.

* 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 10x10x10 cm with a mass of up to 1.33 kg. Multiple units can be combined to form 2U, 3U, and even 6U CubeSats. The CubeSat standard was created by California Polytechnic State University and Stanford University following the first launch of 6 CubeSats in 2003.

SPOTLIGHT:

GRIFEX Technology Validation CubeSat Launched with SMAP

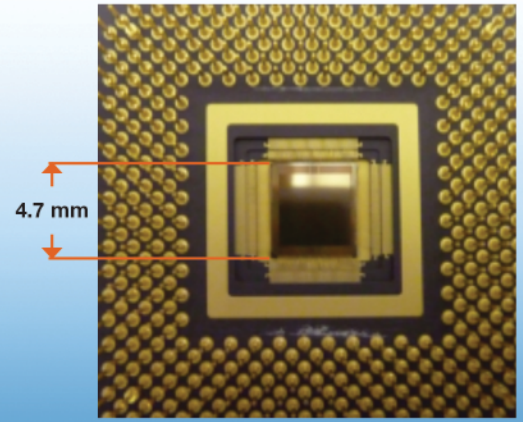
The GEO-CAPE ROIC In-Flight Performance Experiment (GRIFEX) CubeSat, a pre-InVEST space validation project, was launched from Vandenberg Air Force Base on Saturday, January 31, 2015, as an auxiliary payload to the Soil Moisture Active Passive (SMAP) mission.

GRIFEX is a 3-unit (3U, 10x10x30 cm) CubeSat intended to verify the spaceborne performance of a state-of-the-art readout integrated circuit (ROIC) / Focal Plane Array (FPA) with in-pixel digitization and an unprecedented frame rate of 16 kHz. Intended for future imaging interferometry instruments and missions, the technology specifically targets the requirements of the GEOstationary Coastal and Air Pollution Events (GEO-CAPE) mission concept. The ROIC is based on a 2008 ESTO Advanced Component Technology (ACT) investment. Once validated, this technology could enable a mission like GEO-CAPE to make hourly high spatial and spectral resolution measurements of rapidly changing atmospheric chemistry and pollution from geostationary Earth orbit.

GRIFEX was released into space by a Poly-PicoSatellite Orbital Deployer (or P-POD) mounted on the upper stage of the Delta II rocket about 107 minutes after launch. Amateur radio collaborators in Europe were the first to detect the GRIFEX signal beacon about two hours after release. GRIFEX was put into an approximately 650 km circular, polar, low Earth orbit with a 95 minute orbit period.

The GRIFEX team, led by David Rider at the Jet Propulsion Laboratory and James Cutler at the University of Michigan, has reported complete, successful demonstration of the GRIFEX ROIC/Detector in the space environment over the past nine months. As of this report, the spacecraft is still healthy and operational and is expected to continue sending data for many months to come.

Above: An artists depiction of GRIFEX in orbit above Earth. **Below:** The GRIFEX ROIC focal plane array. (Credit: D. Rider, JPL/Caltech)



Future Challenges

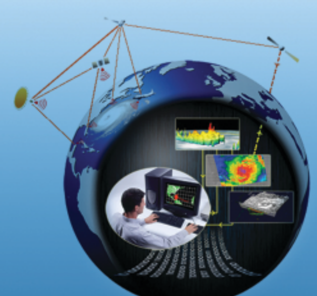
For over 15 years, ESTO investments have anticipated science requirements to enable many new measurements and capabilities. ESTO technologies were already underway to address the priorities outlined by the 2007 National Academies of Science National Research Council Decadal Survey for Earth science, 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.

Looking ahead, there are four broad technology areas that have the potential to expand, support, and even revolutionize the future of Earth science:

Active Remote Sensing Technologies to enable new measurements of the atmosphere, cryosphere and Earth's surface.
- Atmospheric chemistry using lidar vertical profiles
- Ice cap, glacier, sea ice, and snow characterization using radar and lidar
- Tropospheric vector winds using lidar
- Precipitation and cloud measurements using radar

Large Deployable Apertures for future weather, climate, and natural hazard measurements.
- Temperature, water vapor, and precipitation from geostationary orbit
- Soil moisture and sea surface salinity using L-band radar
- Surface deformation and vegetation using radar

Intelligent Distributed Systems using advanced communication, onboard processors, autonomous network control, data compression, and high density storage.
- Long-term weather and climate prediction linking observations to models
- Interconnected sensor webs that share information to enhance observations



Information Knowledge Capture through 3D visualization, holographic memory, and seamlessly linked models.
- Intelligent data fusion to merge multi-mission data
- Discovery tools to extract knowledge from large and complex data sets
- Real time science processing, archiving, and distribution of user products

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

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