NASA ESTO's Strategic Investments in Space-Based Radiometer Technology and Flight Validation

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ABSTRACT

NASA's Earth Science Technology Office (ESTO) performs strategic investments in instrument subsystems, information systems, and most recently the use of CubeSat platforms to advance the technology readiness level (TRL) of relevant Earth Science Decadal Survey technologies to reduce and retire risk before infusion into flight missions. In this talk we describe the ESTO philosophy to strategic investment focusing on radiometer technology development and testing including new work involving spaceborne flight validation of radiometer technologies using CubeSats.

Keywords: CubeSat, InVEST, ESTO, radiometer, MiRaTA, RAVAN

1. INTRODUCTION

The NASA Earth Science Technology Office (ESTO) is a targeted, science-driven, competed, actively managed, and dynamically communicated technology program that utilizes a peer-review proposal-based approach for technology investment to retire risk for future Earth science missions. As part of NASA HQ's Science Mission Directorate Earth Science Division, ESTO specifically develops observation system technologies to provide new instrument and measurement techniques through critical component, sub-system and airborne flight tests. ESTO also develops information system technologies to advance innovative ground, airborne, and on-orbit capabilities for communication processing, management of remotely sensed data, and science data product generation and knowledge. Furthermore, in 2012, ESTO initiated a new program line called In-Space Validation of Earth Science Technologies (InVEST) that fills the gap between ground/airborne technology validation and the need to qualify such systems for spaceborne adoption and use. Technologies adopted through the InVEST program are integrated and flown using the CubeSat platform providing a rapid, low-cost, and innovative means to achieve technical objectives not easily accomplished within sub-orbital testbed environments. Radiometers represent a key area of interest enable science observations via CubeSat flight experiments due to the compatibility of size, weight, and power requirements with this platform, as well as the potential to launch constellations of such systems for coordinated observations. The science community is advancing a number of radiometer flight experiments, many of which are rooted in prior ESTO investments.

Since 1998, ESTO has made numerous investments spanning all aspects of radiometer development from hardware components and instrument subsystems that have been developed and tested in both the laboratory and airborne environment, to related modeling, data processing, and analysis technologies that impact the products that can be produced in atmospheric science. Nevertheless, with the growing interest in using CubeSats as platforms for rapid access to space, radiometers have been identified as a compelling technology to initiate new approaches to spaceborne observations in the microwave spectrum. In particular, due to their inherent size, weight, and power many new observation concepts have been proposed to fly radiometers in space using CubeSats, both as stand alone platforms, and constellations, to usher in new techniques to advance weather and climate science. In this paper, we will introduce the ESTO office, our programmatic strategy and approach to strategic investment in Earth science technologies, our history specifically in the area of space-based radiometer technology development, and our new approach to including CubeSats as a platform to validate these systems for technology maturation.

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2. ESTO'S HISTORY OF RADIOMETER INVESTMENT

2.1 A Review of Radiometer Investment at ESTO

Although ESTO has made recent substantial investments in the development and advancement of various technologies for future Earth Science observations in support of the NRC Decadal Survey[1] our history of supportive investment of Earth science observations dates back to 1998. A search of the ESTO Technology Portfolio database identifies 45 separate investments in radiometer technology across various program areas. The Advanced Component Technologies (ACT) program develops critical subsystems and components for instruments and platforms while the Instrument Incubator Program (IIP) develop robust new instruments and measurement techniques. Both the ACT and IIP programs are part of ESTO's Observation System Program that develops and matures new technology components and instruments for ground and airborne systems. The AIST program develops innovative information systems for on-orbit and ground-based processing of remotely sensed data and the creation of relevant data products. InVEST, as described earlier, is a new program for risk reduction of instrument components and subsystems via space borne flight validation.

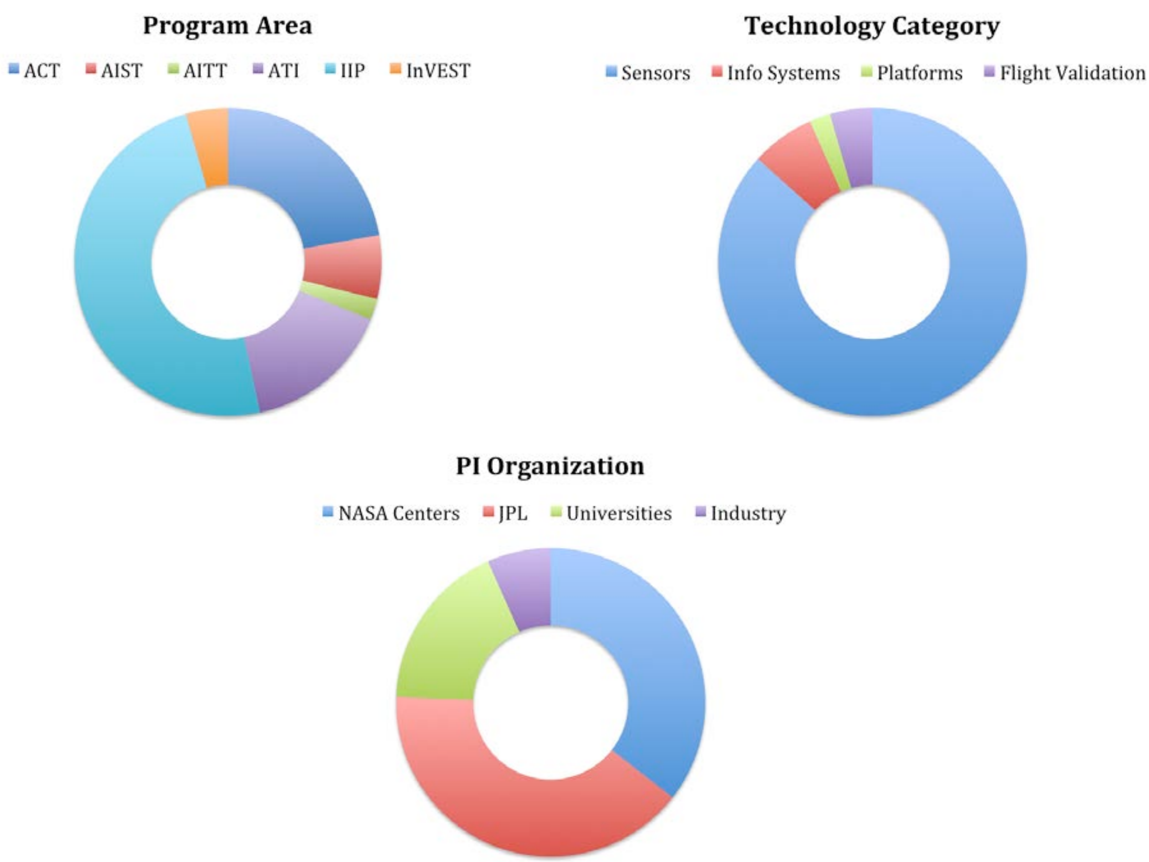
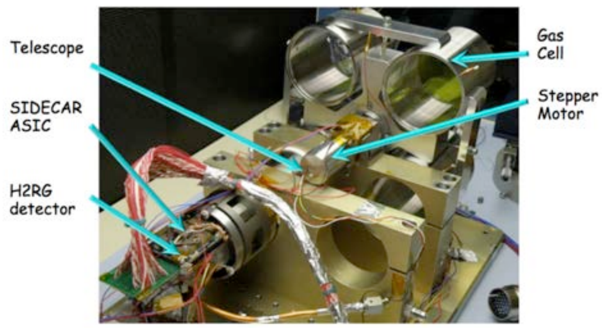
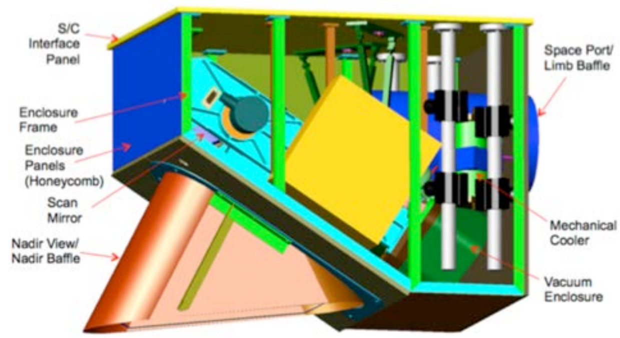


Figure 1. Investment distribution for ESTO sponsored radiometer projects from 1998-2013. These investments have been distributed across a variety of ESTO program areas, technology categories, and organizations as shown.

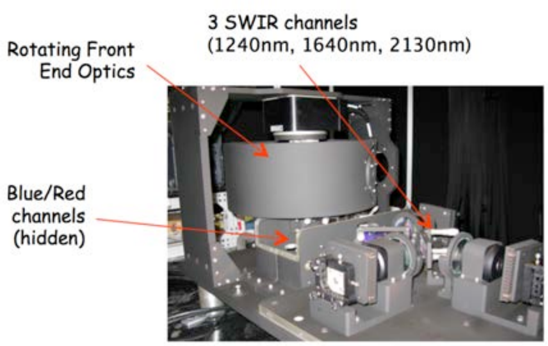
Figure 1 reviews radiometer-related investments based on competitive solicitations awarded from 1998-2013. Most of these investments have come from the observational systems program as components and subsystems have been built, but information systems for these instruments as well as a new CubeSat-based flight experiment are part of this mix as well.

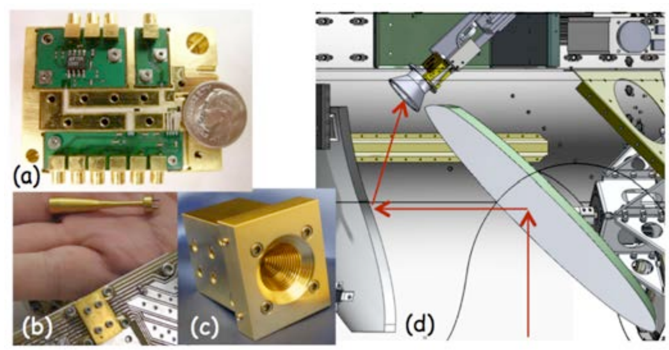
One explanation for the disparity in awarded organizations, specifically NASA center investments compared to all other areas over the years, is the role of radiometers in advancing Earth science measurements. And within this distribution the majority of investments have come via the IIP program to develop radiometer subsystems that have been built and tested in the laboratory as well as flown on various aircraft. Figure 2, for example, shows a handful of current and past radiometer investments applicable to Decadal Survey mission development.





(Left) Infrared Correlation Radiometer for GEO-CAPE (IRCRg) Demonstrator (courtesy LaRC). (Right) Proposed HyspIRI Thermal Infrared Radiometry (PHyTIR) for Earth Science (courtesy JPL).





(Left) Ocean Radiometer for Carbon Assessment Prototype (ORCA) (courtesy GSFC). (Right) Internally-Calibrated Wide-Band Airborne Microwave Radiometer to demonstrate Wet-Tropospheric Path delay Measurements for SWOT (courtesy CSU).

Figure 2. Investment distribution for ESTO sponsored radiometer projects from 1998-2013. These investments have been distributed across a variety of ESTO program areas, technology categories, and organizations as shown.

IRCRg (top left) developed a gas filter correlation radiometer simulation capability demonstrating the SWIR 2.3 micron measurement performance required by the Geostationary Coastal and Air Pollution Events (GEO-CAPE) mission concept. The radiometer, as shown, would be used for carbon monoxide (CO) measurements from GEO where the spectral and noise performance of the prototype were characterized under this task led by Doreen Neil from NASA LaRC in collaboration with NCAR and Johns Hopkins APL. The instrument simulator, in this projects, was used to evaluate mission design questions for GEO-CAPE including the effects of sub-pixel clouds in the field of view and platform jitter during the measurement sequence. The instrument response functions (spectral, spatial, radiometric, and polarization) were quantified and shown to meet the GEO-CAPE requirements as described[2].

PHyTIR (top right) matured key components of a thermal IR radiometer via development of an instrument prototype including a high sensitivity and high throughput focal plane array (FPA) and associated scanning mechanism while also ensuring that the detectors and readouts all meet stringent signal-to-noise and speed specifications. This is a key capability for the HyspIRI mission concept lead by Simon Hook of JPL[3].

ORCA (bottom left) is developing a functional prototype ocean radiometer in support of the Aerosol/Climate/Ecosystem (ACE) mission concept, and for the pre-cursor mission concept called PACE. A 120-deg field-of-view scanning capability, spatial resolution of ~1 km, two gratings to provide 5nm spectral resolution from the UV to NIR, risk reduction of the custom detectors, and verification of the mechanical and electronic subsystem synchronization are the key objectives of the task. Led by PI Gerhard Meister of NASA GSFC co-investigators include NIST and SBIG. The system level characterization and calibration will be performed to NIST standards[4].

The airborne microwave radiometer for SWOT (bottom right) will reduce risk associated with wet-path delay corrections for the SWOT mission concept. This project, led by Steve Reising of Colorado State University with co-investigators from UCLA and JPL, has designed and fabricated internally calibrated, wide-band and mm-wave window and sounding radiometer channels that have been integrated into an airborne radiometer instrument. The system will allow measurement of fine-scale water vapor based on measurements over oceans, coastal areas, and land[5].

As previously mentioned there were many radiometer investments made over the years that developed components and systems for ground and airborne testing. These range from simulation tools used to design and characterize radiometers for future mission concepts, cloud-ice radiometers, synthetic aperture radiometers for remote sensing, rainfall, sea surface salinity, and instruments for snow measurements. The fundamental size, weight, and power (SWAP) characteristics of such systems, however, have encouraged some to design and integrate radiometers for CubeSat flight systems with the potential to enable constellation-based measurements for high spatial and temporal observations. ESTO has recently pursued investments in this area.

2.2 CubeSat-Based Radiometer Investments

Over the years, ESTO has made substantial investments in the development of low power/noise radiometer receivers. The Radiometer Atmospheric CubeSat Experiment (RACE) is a 3U CubeSat development, led by JPL PI Boon Lim in collaboration with University of Texas at Austin to advance and demonstrate radiometer technologies while measuring the liquid water path and precipitable water vapor essential to the water cycle and Earth's energy budget understanding[6]. The primary payload is an ESTO developed radiometer that will make measurements at the 183 GHz water vapor line.

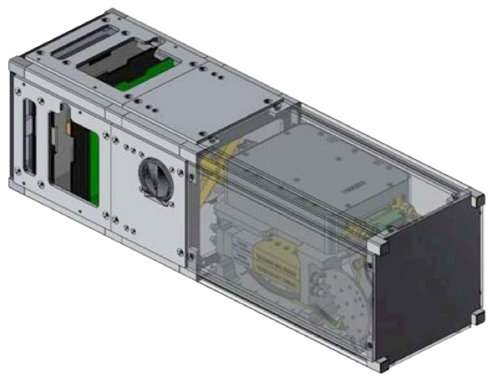


Figure 3. CAD model of the UT Austin designed RACE CubeSat bus with the JPL developed radiometer payload within the 3U (10x10x10 cm) structure (courtesy U. Texas at Austin and JPL).

This will be a spinning CubeSat planned for launch on CRS-4 in the fall of 2014 under NASA's CubeSat Launch Initiative. It should be noted that other CubeSat-based radiometers, such as MIT's MicroMAS, operating at the 118 GHz range, have been developed and are also awaiting launch.

2.3 ESTO's InVEST Program and Radiometer CubeSat Flight Projects

In 2012, ESTO initiated the In-Space Validation of Earth Science Technologies (InVEST) as a means to perform in-orbit technology validation and risk reduction for instrument components and small instruments that could not be fully tested or validated in ground-based testbeds. Four selections were made, two of which are advancing radiometer technology capabilities; RAVAN, led by William Swartz of John's Hopkins APL, and MiRaTA led by Kerri Cahoy of MIT.

MiRaTA, the Microwave Radiometer Technology Acceleration CubeSat, will perform in-space validation of new microware radiometer and GPS Radio Occultation (GPSRO) technology based on a 3U CubeSat design[7]. The system will take measurements at the ~55 GHz (temperature), ~183 GHz (water vapor), and ~207 GHz (cloud ice) bands. Atmospheric GPSRO will also be demonstrated along with comparison of radiometer and GPSRO fields-of-view for cross validation while linking radiometer calibration to NIST traceable standards. In the end, this system will validate new GPS receiver technology and antenna array technology to support tropospheric radio occultation from a CubeSat. It will also test a new radiometer calibration method based on concurrent GPSRO measurements. This work, while led by

MIT, includes collaborators from MIT/LL, The Aerospace Corporation, Utah State University, and NASA Wallops Flight Facility.

RAVAN, Radiometer Assessment using Vertically Aligned NanoTubes, will build and flight qualify a radiometer using vertically aligned carbon nanotubes as the absorber material demonstrating the effectiveness of the instrument for measuring total outgoing radiance[8]. This will be a precursor to a potential constellation system for measuring Earth radiation imbalance. The radiometer performance will be compared against a laboratory reference. This system is lead by JHU/APL with collaborators from NASA GSFC and L-1 Standards and Technology.

Figure 4. Renderings of the RAVAN (courtesy JHAPL) and MiRaTA (courtesy MIT Lincoln Labs and MIT) CubeSat Spacecraft led by William Swartz of John's Hopkins Applied Physics Laboratory and Kerri Cahoy of the Massachusetts Institute of Technology, respectively.

3. FUTURE AND SIGNIFICANCE FOR EARTH SCIENCE

ESTO's role is to invest in multiple technologies that are responsive to NASA's guidance documents such as the Climate Centric Architecture, the Decadal Survey for Earth Science, and other strategic and implementation plans, to advance measurements to improve our understanding of the Earth system. A wide variety of capabilities in information and observational systems are simultaneously pursued, but the radiometer investments are one example that spans all aspects of the ESTO program. We expect these radiometer investments to successfully impact climate measurements, and with the addition of flight opportunities to advance the technology via small satellites a future that could include constellation measurements to advance climate science may be realized.

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