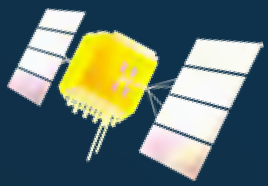
National Aeronautics and
Space Administration

Earth Science Technology Office Annual Report 2022



Executive Summary

As you'll read in the pages that follow, 2022 was another full and productive year for technology development at the NASA Earth Science Technology Office (ESTO), with numerous successes advancing new technologies for Earth science as well as the competitive selection of new projects.

In fiscal year 2022 (FY22), ESTO continued to build upon its 24-year heritage of technology development. This year, 43% of active ESTO technology projects advanced at least one Technology Readiness Level (TRL), and at least 10 active and completed projects were transitioned to follow-on development efforts or infused into Earth observing missions, operations, or commercial applications. We are particularly proud to report that at least 119 students – high school through PhD – were directly involved in ESTO-funded projects this year.

A new program element was added to the ESTO portfolio this year: Technology Development for support of Wildfire Science, Management, and Disaster Mitigation (FireSense Technology). FireSense Technology, working with interagency partners such as NOAA, U.S. forestry Service, CAL FIRE, and the National Interagency Fire Center, will leverage NASA resources to improve the end-to-end management of wildfires in the United States and around the world. Over the next several years, FireSense Technology will execute a series of airborne field campaigns to test novel technologies for the observation and impact reduction of wildfires.

New projects were added through competitive solicitations under the Instrument Incubator Program (IIP), the Decadal Survey Incubation (DSI) program, and the Advanced Information Systems Technology (AIST) program, in November 2021, April 2022, and May 2022 respectively. And as of publication, three program elements – FireSense Technology, the Advanced Component Technologies (ACT) program, and the Sustainable Land Imaging - Technology (SLI-T) program – expect to announce new awards in FY23. We welcome these new cohorts of technologists and look forward to the contributions they will make.

Finally, we note the phased retirement of Bob Bauer, who has served as ESTO's Deputy Director for the last 12 years. Bob's steady leadership has enabled ESTO to thrive amidst numerous challenges and transitions.

Pamela S. Millar
Program Director

Robert A. Bauer
Deputy Program Director

On February 19, 2022, Cygnus NG-17 launched from Wallops Island, Virginia, ferrying ESTO-funded CubeSat Nanosat Atmospheric Chemistry Hyperspectral Observation System (NACHOS-1) to the International Space Station to await its deployment on June 30, 2022. Credit: NASA

ABOUT ESTO

As the technology development function within NASA's Earth Science Division, the Earth Science Technology Office (ESTO) performs strategic planning and manages the development of a broad range of nascent technologies for future science measurements. ESTO employs an open, flexible, science-driven strategy and relies on competition and peer review to select the best cutting-edge technologies, from advanced sensors aboard miniature satellites to software tools that plan new observations and harmonize, fuse, and analyze large data sets from various sources.

Our approach to Technology Development:

Strategy: Engage with the Earth science community to plan investments through careful analyses of science requirements

Selection: Fund technology development through periodic, competitive solicitations and partnership opportunities

Management: Review and advise funded technology projects on progress and performance

Infusion: Encourage and facilitate the use of mature technologies in science measurements

Table of Contents

174 Projects Active in FY22

59 Projects Added

32 Projects Graduated

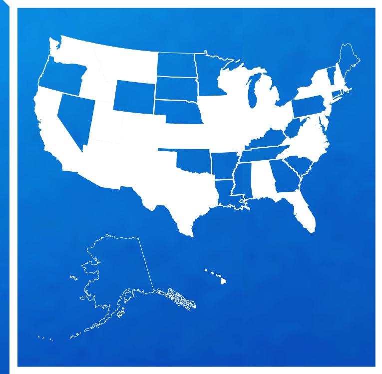
6 CubeSats On Orbit

6 Projects Airborne Tested

69 Unique PI Orgs

26 States

121 Unique Co-I Orgs



27 States

110 Journal Articles

304 Conference Publications

3 Patents

119 Students

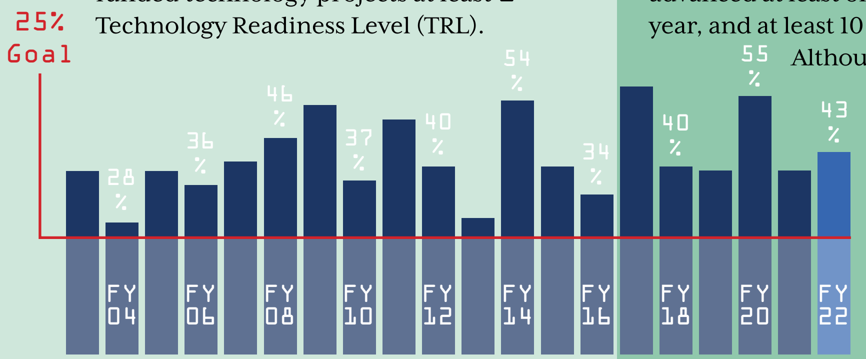
37 Universities

2022 Metrics

With over 1,050 technology investments made since 1999 and an active portfolio of 174 projects during FY22 (October 1, 2021, through September 30, 2022), ESTO drives innovation, enables future Earth science observations, and strengthens NASA's reputation for developing and advancing leading-edge technologies. To clarify the FY22 achievements, what follows are the year's results tied to ESTO's performance metrics.

01 GOAL

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



Percentage of Active Projects that advanced at least 1 TRL during each Fiscal Year.

FY 2022 Result

43% of ESTO technology projects funded during FY22 advanced at least one TRL over the course of the fiscal year, and at least 10 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 annual TRL advancement for all years going back to 1999 is 42%.

02 GOAL

Mature at least 3 technologies to the point where they can be demonstrated in space or in a relevant operational environment.

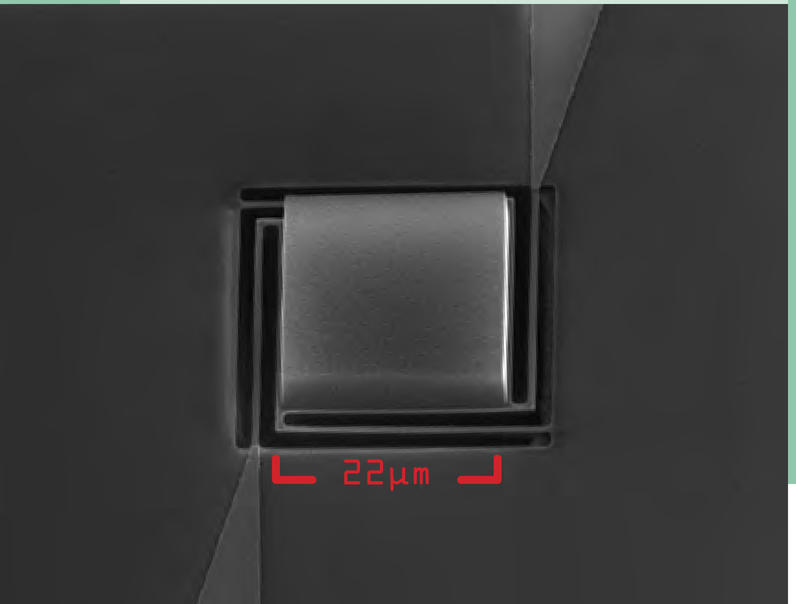
FY 2022 Result

In this fiscal year, at least 8 ESTO projects achieved infusion into science measurements, airborne campaigns, data systems, or follow-on development activities. 3 notable examples follow.

Infusion Highlight — Libera Detectors

Uncooled microbolometer detector technology developed by the Black Array of Broadband Absolute Radiometers (BABAR) project (PI: Michelle Stephens, NIST; ACT-17) has been selected for use on the Libera instrument which will fly on NOAA's operational Joint Polar Satellite System-3 (JPSS-3) satellite. The microbolometer arrays feature tiny « **vertically aligned carbon nanotube (VACNT) absorbers, shown here with electron microscopy magnification**. Scheduled to launch in 2027, JPSS-3 and the Libera instrument will make radiation budget measurements of the Earth, continuing the record of measurements made by the CERES instruments.

Image credit: Michelle Stephens, NIST

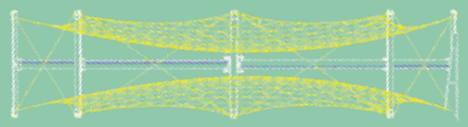


Infusion Highlight — Technology Heritage on INCUS

In November 2021, NASA selected a new Earth science mission – Investigation of Convective Updrafts (INCUS) – through the Earth Venture Mission-3 (EVM-3) solicitation. The mission, consisting of three formation-flying SmallSats to study the behavior of tropical storms and thunderstorms, is made possible by more than a decade of ESTO technology investments, including:

« The **RainCube (Radar in a CubeSat)** project (PI: Eva Peral, Jet Propulsion Laboratory (JPL); InVEST-15) combined miniaturization, pulse compression, and a deployable antenna design, which were all successfully demonstrated on orbit and are now being utilized by INCUS.

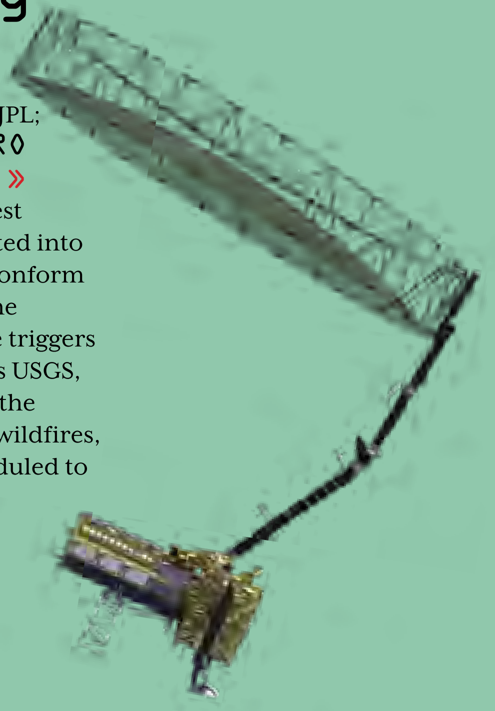
RainCube, in turn, was enabled by the **Ka-Band Highly-Constrained Deployable Antenna** project (PI: Yahya Rahmat-Samii, JPL; ACT-13), which designed, prototyped, and developed compact 1- and 2-meter mesh antennas and feed horns for use by precipitation radars on CubeSats/SmallSats.



Lastly, the **TEMPEST-D (Temporal Experiment for Storms and Tropical Systems)** project (PI: Steve Reising, Colorado State University; Earth Venture Tech 2014) developed and demonstrated a new, low-cost, compact microwave radiometer that will be hosted on one of the three INCUS satellites.

Infusion Highlight — Smart Tasking for NISAR

A Smart Tasking tool (PI: Cathleen Jones, JPL; AIST-19) was adopted by the NASA-ISRO Synthetic Aperture Radar » (NISAR) for its urgent response request handling system and has been incorporated into the mission with some adaptations that conform to the mission's specific requirements. The technology architecture will use available triggers from major U.S. federal agencies – such as USGS, Forest Service, etc – to automatically task the satellite to observe unfolding events like wildfires, volcanoes, or earthquakes. NISAR is scheduled to launch in 2024.



03 GOAL »

Enable a new science measurement or significantly improve the performance of an existing technique. Several projects satisfied this goal in FY22. One notable example follows:

Project Highlight
HARP Pioneers New Earth Observation Technology

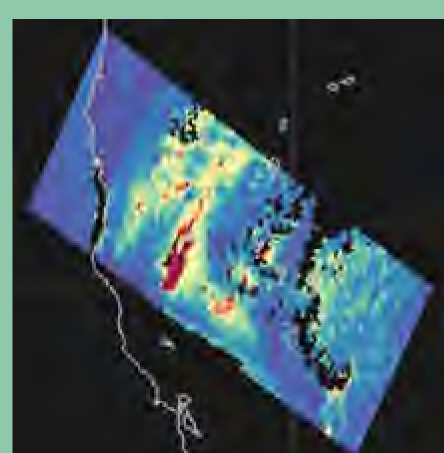
After two years of successful demonstrations on orbit, the Hyper Angular Rainbow Polarimeter (HARP), a 3-unit CubeSat developed at the University of Maryland, Baltimore County, reentered Earth's atmosphere in early April 2022. Launched to the International Space Station in November 2019 and subsequently deployed in February 2020, HARP pioneered new technologies for observing cloud and aerosol properties from space – crucial measurements for the study of air pollution and climate change.

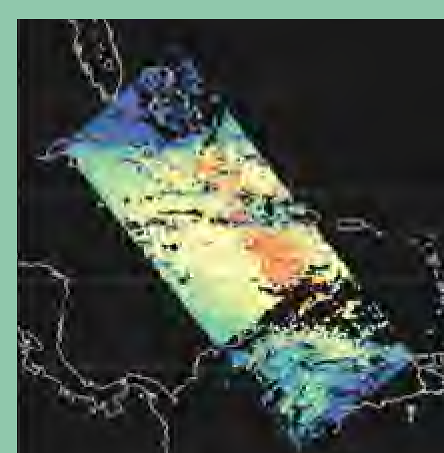
Specifically, HARP validated that an experimental, compact imaging polarimeter – which observes how light scatters off various particles to determine their size, shape, and chemical composition – can be used to gather atmospheric data onboard a cost-efficient CubeSat. The HARP polarimeter uses a unique prism to split three identical images into independent detector arrays, allowing HARP to achieve highly accurate, simultaneous imagery of three polarization states with minimal hardware.

On orbit, HARP observed Earth from multiple viewing angles, four wavelengths, and three polarization channels, and demonstrated measurements of aerosols and cloud properties. HARP data were compared to AERONET (AErosol RObotic NETwork) ground-based radiometer observations and showed very good agreement at multiple locations. The HARP team also conducted comparative observations with the MODerate resolution Imaging Spectroradiometers (MODIS) onboard the Aqua and Terra satellites, as well as the Advanced Baseline Imagers (ABI) onboard the GOES-R series spacecraft.

NASA missions are already utilizing HARP-inspired instruments to monitor aerosol-cloud interactions in Earth's atmosphere from aircraft and space platforms. These include NASA's ACEPOL and LMOS airborne campaigns, which used AirHARP as an airborne sensor to observe aerosol and clouds from up to 20km above the surface of Earth, and NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission, slated to launch in 2023, which will use HARP2 to look at Earth's atmosphere and ocean ecosystems.

HARP Principal Investigator Vanderlei Martins with the HARP CubeSat. Credit: Vanderlei Martins, UMBC





» Aerosol optical depth (AOD) retrievals from the HARP CubeSat validation mission – left: the California-Oregon Fire from August 25, 2020; right: Saharan Dust Transport from June 23, 2020. Credit: Vanderlei Martins, UMBC

2022 Program Updates

FireSense Technology

A new program element was added to the ESTO portfolio this year: Technology Development for support of Wildfire Science, Management, and Disaster Mitigation (FireSense Technology) will seek new, innovative Earth system observation capabilities to predict and manage wildfires and their impacts. ESTO's FireSense Technology program is partnering with NASA's Applied Sciences and Research and Analysis elements, the Aeronautics Research Mission Directorate (ARMD), and the Small Business Innovative Research (SBIR) program.

FireSense will work closely with interagency partners such as NOAA, the U.S. Forestry Service, the California Department of Forestry and Fire Protection, the National Interagency Fire Center, and others. In doing so, FireSense Technology will leverage NASA resources to improve the end-to-end management of wildfires in the United States and around the world.

Over the next 5-6 years, FireSense Technology will execute a series of airborne field campaigns to test novel technologies for assessing the impact of wildfires. These technologies will make use of broad capabilities in instrument and information technology, along with new observing platforms in space, in the air, and on the ground.

The first FireSense Technology solicitation opened in June 2022 and will accept proposals on a rolling basis, with selections announced quarterly. See page 26 for more on FireSense, and visit https://esto.nasa.gov/firetech/ to learn about the ongoing solicitation.

Decadal Survey Incubation

A new program element created in 2020, Decadal Survey Incubation (DSI) seeks to accelerate the readiness of two high-priority observables needing science-requirement refinement, technology development, and/or other advancements prior to cost-effective flight implementation. DSI was recommended by the National Academies in the 2017 Earth Science Decadal Survey to target the Planetary Boundary Layer (PBL) and Surface Topography and Vegetation (STV) areas. These two fields are complex and dynamic systems with important science objectives and societal applications. Advancing technology to support these areas will improve observational capabilities that may unlock new insights into a wide variety of Earth processes.

In 2020, two study teams were competitively selected to "identify methods and activities for improving the understanding of and advancing the maturity of the technologies applicable to these two targeted observables and their associated science and applications priorities." Each team produced a report that helped inform the DSI solicitation for proposals released in FY21.

6 Technology Projects Selected in FY 22

High Resolution PBL Profiling with LEO-LEO Occultation (HiPPO) - Chi Ao, JPL

Deployable MetaLens for G-Band Earth Science Applications - Richard Hodges, JPL

Hyperspectral Capability for CoSMIR: Enhancing Capability for Future PBL Suborbital Campaigns and Enabling PBL Science from Space - Rachael Kroodsma, University of Maryland, College Park

Embedded PNT Module for Distributed Radar Sensing - Patrick Rennich, Aloft Sensing

Multi-Sensor Multi-Platform Surface Topography and Vegetation Structure Data Fusion Information System (STV-FIS) - Sassan Saatchi, JPL

Advanced Information Systems to Fill STV Gaps: Next-Generation Stereo+Lidar Fusion and Sensor Technology - David Shean, University of Washington, Seattle

Abstracts for these awards are available online: https://esto.nasa.gov/project-selections-for-dsi-21/

Advanced Information Systems Technology

Advanced information systems play a leading role in the collection, processing, integration, analysis, understanding, and utilization of vast amounts of Earth science data, both in space and on the ground. Advanced computer intelligence and technology concepts that enable novel acquisition, discovery, fusion, and analytics strategies for terabytes of diverse 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 space where the information pipeline begins, to the end user where knowledge is advanced.

Recently, AIST has focused on the following areas:

New Observing Strategies

This thrust helps develop and evolve new ways of designing novel Earth observation systems and capabilities to incorporate technological advances, like constellations of small satellites and smarter sensors, and information dynamically gathered from space, air, and ground-based sources.

Analytic Collaborative Frameworks

Once Earth observing missions are in operation, very large amounts of data are collected, often in differing formats and of diverse resolutions. Agile analytic frameworks enhance science investigations by fusing disparate datasets and pioneering visualization and analytics tools, including machine learning as well as relevant computing environments.

Earth System Digital Twins

These frameworks seek to mirror the Earth with state-of-the-art Earth system and human models and simulations, timely and relevant observations, and analytic tools, enabling the exploration of various hypothetical and predictive scenarios.

64 Projects Active in FY22

19 Projects Graduated

Cloud-based Analytic Framework for Precipitation Research (CAPRi) - John Beck, University of Alabama Huntsville

StereoBit: Advanced Onboard Science Data Processing to Enable Future Earth Science - James Carr, Carr Astronautics Corporation

NeMO-Net: The Neural Multi-Modal Observation & Training Network for Global Coral Reef Assessment - Ved Chirayath, NASA ARC

Quantifying Uncertainty and Kinematics of Earthquake Systems (QUAKES-A) Analytic Center Framework - Andrea Donnellan, JPL

Multi-scale Methane Analytic Framework - Riley Duren, JPL

New Observing Strategies Testbed (NOS-T) - Nathaniel Jay Ellis, KBR

Proposed Integrated New Observing Strategies Mission Design Tool - Paul Grogan, Stevens Institute of Technology

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

Smart On-Demand Analysis of Multi-Temporal and Full Resolution SAR ARDs in Multi-Cloud & HPC - Hook Hua, JPL

AMP: An Automated Metadata Pipeline - Beth Huffer, Lingua Logica

Valid time-series analyses of satellite data to obtain statistical inference about spatiotemporal trends at global scales - Anthony Ives, University of Wisconsin

An Analytic Center for Biodiversity and Remote Sensing Data Integration - Walter Jetz, Yale University

SPCTOR: Sensing-Policy Controller and OptimizeR - Mahta Moghaddam, University of Southern California

Ground Penetrating Radar (GPR) Soil Moisture Integration - Mahta Moghaddam, University of Southern California

NASA Evolutionary Programming Analytic Center (NEPAC) for Climate Data Records, Science Products and Models - John Moisan, NASA GSFC

A Science-Focused, Scalable, Flexible Instrument Simulation (OSSE) Toolkit for Mission Design - Derek Posselt, JPL

Ocean Carbon Cycle NOS Demonstration Study - Laura Rogers, NASA LaRC

The bridge from canopy condition to continental scale biodiversity forecasts, including the rare species of greatest conservation concern - Jennifer Swenson, Duke University

Supporting Shellfish Aquaculture in the Chesapeake Bay using Artificial Intelligence to Detect Poor Water Quality through Sampling and Remote Sensing - Stephanie Schollaert Uz, NASA GSFC

28 Projects Added in FY22

Pixels for Public Health: Analytic Collaborative Framework to Enhance Coastal Resiliency of Vulnerable Populations in Hampton Roads, Virginia - Thomas Allen, Old Dominion University Research Foundation

Digital Twin Infrastructure Model for Agricultural Applications - Rajat Bindlish, NASA GSFC

Sensor-in-the-Loop Testbed to Enable Versatile/Intelligent/ Dynamic Earth Observation (VIDEO) - William Blackwell, Massachusetts Institute of Technology/Lincoln Lab

Detection of artifacts and transients in Earth Science observing systems with machine learning - Yehuda Bock, University of California, San Diego

Edge Intelligence for Hyperspectral Applications in Earth Science for New Observing Systems - James Carr, Carr Astronautics Corporation

Intelligent Long Endurance Observing System - Meghan Chandarana, NASA ARC

An Analytic Collaborative Framework for the Earth System Observatory (ESO) Designated Observables - Arlindo da Silva, NASA GSFC

Innovative geometric deep learning models for onboard detection of anomalous events - Yulia Gel, University of Texas, Dallas

A hosted analytic collaborative framework for global river water quantity and quality from SWOT, Landsat, and Sentinel-2 - Colin Gleason, University of Massachusetts, Amherst

DTAS: A prototype Digital Twin of Air-Sea interactions - Alison Gray, University of Washington, Seattle

GEOS Visualization And Lagrangian dynamics Immersive eXtended Reality Tool (VALIXR) for Scientific Discovery - Thomas Grubb, NASA GSFC

Stochastic Parameterization of an Atmospheric Model Assisted by Quantum Annealing - Alexandre Guillaume, JPL

Thematic Observation Search, Segmentation, Collation and Analysis (TOS2CA) System - Ziad Haddad, JPL

Towards a NU-WRF based Mega Wildfire Digital Twin: Smoke Transport Impact Scenarios on Air Quality, Cardiopulmonary Disease and Regional Deforestation - Milton Halem, University of Maryland Baltimore County

A scalable probabilistic emulation and uncertainty quantification tool for Earth-system models - Matthias Katzfuss, Texas A & M, College Station

Development of a next-generation ensemble prediction system for atmospheric composition - Christoph Keller, Universities Space Research Association, Columbia

Open Climate Workbench to support efficient and innovative analysis of NASA's high-resolution observations and modeling datasets - Huikyo Lee, JPL

Ecological Projection Analytic Collaborative Framework (EcoPro) - Seungwon Lee, JPL

An Intelligent Systems Approach to Measuring Surface Flow Velocities in River Channels - Carl Legleiter, USGS Reston

Reproducible Containers for Advancing Process-oriented Collaborative Analytics - Tanu Malik, De Paul University

Terrestrial Environmental Rapid-Replicating Assimilation Hydrometeorology (TERRAHydro) System: A machine-learning coupled water, energy, and vegetation terrestrial Earth System Digital Twin - Craig Pelissier, Science Systems and Applications

Knowledge Transfer for Robust GeoAI Across Space, Sensors, and Time via Active Deep Learning - Saurabh Prasad, University of Houston

Integration of Observations and Models into Machine Learning for Coastal Water Quality - Stephanie Schollaert Uz, NASA Goddard Space Flight Center

3D-CHESS: Decentralized, distributed, dynamic and context-aware heterogeneous sensor systems - Daniel Selva, Texas A&M Engineering Experiment Station

Kernel Flows: emulating complex models for massive data set - Jouni Susiluoto, JPL

A New Snow Observing Strategy in Support of Hydrological Science and Applications - Carrie Vuyovich, NASA GSFC

SLICE: Semi-supervised Learning from Images of a Changing Earth - Brian Wilson, JPL

Coupled Statistics-Physics Guided Learning to Harness Heterogeneous Earth Data at Large Scales - Yiqun Xie, University of Maryland, College Park

Instrument Incubator Program

50 Projects Active in FY 22

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.

17 Projects Added

Separated Thinned Array for Sensing of Ice Sheets (STASIS) - Alexander Akins, JPL

Rydberg Radar: A Quantum Architecture Covering the Radio Window for Multi-Science Signal of Opportunity Remote Sensing with Focus on Land Surface Hydrology - Darmindra Arumugam, JPL

Quantum Gravity Gradiometry in Hybrid Architectures with Satellite-to-Satellite Tracking for Spaceborne Earth System Mass Change Measurements - Srinivas Bettadpur, University Of Texas, Austin

Configurable Reflectarray for Electronic Wideband Scanning Radiometry (CREWSR) - William Blackwell, Massachusetts Institute of Technology/Lincoln Lab

Simplified Gravitational Reference Sensors for Future Earth Constellations - John Conklin, University of Florida, Gainesville

Multi-Functional Lidar Measurements to Identify and Characterize Marine Debris using Time-Resolved Fluorescence - Madeline Cowell, Ball Aerospace & Technologies Corporation

Photonic Integrated Circuits (PICs) in Space: The Hyperspectral Microwave Photonic Instrument (HyMPI) - Antonia Gambacorta, NASA GSFC

Combining Distributed RF and Multi-spectral Optical Observations for a Spaceborne 3-D Lightning Measurement Concept - Patrick Gatlin, NASA MSFC

Compact Fire Infrared Radiance Spectral Tracker (c-FIRST) - Sarath Gunapala, JPL

Compact Optomechanical Accelerometers for Space Geodesy - Felipe Guzman, Texas A&M Engineering Experiment Station

Compact Total and Spectral Solar Irradiance Sensor (CTSIS) Mission Concept Study - David Harber, University Of Colorado, Boulder

Flexible Configuration Distributed Synthetic Aperture Digital Beamforming Radar (FlexSAR) - Yunling Lou, JPL

Metamaterial-based Super Spectral Filter Radiometers for Atmospheric Sounding of Temperature and Water Vapor - Richard Lynch, Atmospheric & Environmental Research

Microwave Barometric Radar and Sounder (MBARS) - Matthew McLinden, NASA Goddard Space Flight Center

SNOWWI: Snow Water-equivalent Wide Swath Interferometer and Scatterometer - Paul Siqueira, University of Massachusetts, Amherst

Quantum Parametric Mode Sorting (QPMS) Lidar - Carl Weimer, Ball Aerospace & Technologies Corporation

HALE InSAR for Continual and Precise Measurement of Earth's Changing Surface - Lauren Wye, Aloft Sensing

5 Projects Graduated

Integrated Inertial Sensors and Laser Ranging Instruments for Small Satellite Earth Geodesy Constellations - John Conklin, University of Florida

Metagratings and Optics for High resolution Multispecies Atmospheric Profiler (HiMAP) - Dejian Fu, JPL

Assessment of Quantum parametric mode sorting (QPMS) for snow depth and snow property measurements - Yongxiang Hu, NASA LaRC

Multi-Application Smallsat Tri-band Radar - Tushar Shenoy, JPL

SWIRP: Compact Submm-Wave and LWIR Polarimeters for Cirrus Ice Properties - Dong Wu, NASA GSFC

In-space Validation of Earth Science Technologies

12 Projects Active in FY 22

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.

1 Project Graduated

Compact Solar Spectral Irradiance Monitor Flight Demonstration - Erik Richard, University of Colorado, Boulder

Sustainable Land Imaging - Technology

For over 40 years, the Landsat series of satellites has been providing a continuous stream of moderate resolution, multispectral images that have been used by a broad range of specialists to analyze our world. To continue the mission of Landsat, NASA initiated the Sustainable Land Imaging – Technology (SLI-T) program to explore innovative technologies to achieve Landsat-like data with more efficient instruments, sensors, components, and methodologies.

9 Projects Active in FY 22

Advanced Component Technologies

25 Projects Active in FY 22

Advanced Component Technologies (ACT) implement technology developments to advance state-of-the-art instruments. The ACT program funds the research, development, and demonstration of component- and subsystem-level technologies to reduce the risk, cost, size, mass, and development time of missions and infrastructure.

5 Projects Graduated

Computational Reconfigurable Imaging Spectrometer (CRISP) – Adam Milstein, MIT Lincoln Lab

Metamaterial-based, Low SWaP, Robust and High-Performance Hyperspectral Sensor for Land and Atmospheric Remote Sensing - Igor Bendoym, Phoebus Optoelectronics

Advanced Photon-Counting Detector Subsystem for Spaceborne Lidar Applications - John Smith, NASA LaRC

Plasmonic Enhanced Long-Wavelength Photodetectors for Earth Radiation Budget Instruments - Michael Cooney, NASA LaRC

Graphene-Based Detector Array Technology for NASA Applications - Ashok Sood, Magnolia Optical Technologies

Finding Water

A Signals of Opportunity Approach to Root Zone Soil Moisture Measurement

Extreme drought afflicts more than 20% of the American West, impacting everything from food prices to conservation efforts. Mitigating the effects of this ongoing drought requires advanced sensors for monitoring the water cycle and managing dwindling water supplies more efficiently.

"NASA has a lot to offer in this regard. Space-based sensors provide us with a unique vantage point for observing Earth systems like snow accumulation and melt," said Simon Yueh, a research scientist at NASA's Jet Propulsion Laboratory (JPL).

Alongside a team of fellow NASA researchers, Yueh and his colleagues at JPL developed Signals of Opportunity Synthetic Aperture Radar (SoOpSAR), a unique remote sensor that parses radio signals produced by telecommunications satellites for information about mountainous snowpacks. With just four or five SoOpSAR satellites, researchers could monitor mountainous snowpacks on a global scale.

"The idea is to leverage signals from other communications sources, such as GPS. This allows us to just build a receiver to capture reflected signals as they ricochet back into space," said Yueh.

By taking advantage of existing high-power radio transmissions already bouncing off of Earth's surface, SoOpSAR can collect detailed data describing fallen snow with no active transmitter of its own. This allows SoOpSAR to reduce weight and power consumption without sacrificing data resolution.

"If we use a constellation of these small satellites, we can combine the signals they receive in a coherent way to sharpen the ground resolution," said Yueh.

Yueh's project stems from other NASA efforts to develop "signals of opportunity" radar instruments. NASA's Signals of Opportunity P-band Investigation (SNOOPI) uses the same technology to observe Root Zone Soil Moisture (RZSM) – a critical component of agricultural models.

To provide water users with effective data describing snowpacks, Yueh said that an instrument needs to observe mountainous regions at a resolution of just hundreds of meters per pixel with ability to penetrate foliage and deep snowpack. This means transmitting within the P-band wavelength, a lower frequency than the L-band Global Navigation Satellite System frequencies currently in use by NASA CYGNSS instruments.

P-band transmissions are typically reserved for land and satellite mobile services, as well as TV broadcasting. There are no restrictions for receiving P-band transmissions produced by communication satellites, which are encrypted and indecipherable. With just a small radio receiver fixed to a CubeSat, SoOpSAR would allow Yueh and his colleagues to comb those transmissions for information about mountainous snowpacks.

"One of the most complex parts of a big, powerful radar is that it's very power hungry. A high powered radar transmitter for space missions may require 1,000 or 2,000 kilowatts of electricity, large deployable antenna and solar panels, greatly increasing the size and weight of instruments dedicated to broadcasting within that wavelength. That makes the spacecraft very big and very expensive," said Yueh.

In contrast, SoOpSAR only consumes about 20-30 watts and would be small enough to fit onboard a small satellite platform.

Yueh explains that small satellites, which are far less expensive to produce, deploy, and operate in space, can already observe Earth systems like severe weather, wildfires, and atmospheric aerosols. But CubeSats are currently ineffective at studying mountainous snowpacks, which often settle around dense forest canopies and change greatly within relatively small distances.

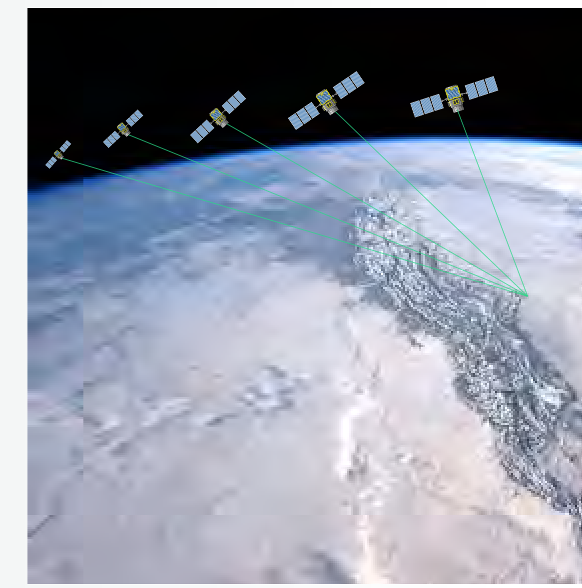
"So how do you penetrate those canopies to look at the snow? You need more power, but more power means more weight, larger satellites, and more expensive missions based on current radar technologies," said Yueh. "SoOpSAR offers a cost-effective alternative."

Mountainous snowpacks are critical components of Earth's water cycle, making up as much as 75% of all freshwater in the American west alone.

"If you look at just the Tibetan plateau, the population supported by that is in the billions. If, someday, the amount of water from snow changes significantly, what do you think would happen? There's going to be a global impact," said Yueh.

As human-made climate change continues to alter our environment, Yueh said that developing advanced missions to better understand the state of Earth's snowpacks is of paramount importance.

"I think all of us need to be very, very concerned about this snow distribution pattern and how it might change in the mountainous regions. Some people say, 'well, it only impacts people who live in these areas, so who cares?' We care. Billions of people care," said Yueh.



Artist's rendering of a potential SoOpSAR constellation. Credit: NASA

Making Space for Data

Leveraging AI to Prioritize Observations and Process Information

Earth-observing instruments can gather a world's worth of information each day. But transforming that raw data into actionable knowledge is a challenging task, especially when instruments have to decide for themselves which data points are most important.

"There are volcanic eruptions, wildfires, flooding, harmful algal blooms, dramatic snowfalls, and if we could automatically react to them, we could observe them better and help make the world safer for humans," said Steve Chien, a JPL Fellow and Head of Artificial Intelligence at NASA's Jet Propulsion laboratory.

A team including engineers from JPL and the companies Qualcomm and Ubotica is developing AI algorithms in space that could help future missions process raw data more efficiently.

These AI algorithms allow instruments to identify, process, and downlink prioritized information automatically, reducing the amount of time it would take to get information about events like a volcanic eruption from space-based and planetary instruments to scientists on the ground.

These AI algorithms could help space-based remote sensors make independent decisions about which Earth phenomena are most important to observe, such as wildfires.

"It's very difficult to direct a spacecraft when we're not in contact with it, which is the vast majority of the time. We want these instruments to respond to interesting features automatically," said Chien.

Chien prototyped the algorithms using commercially available advanced computers onboard the International Space Station (ISS). During several separate experiments, Chien and his team investigated how well the algorithms ran on Hewlett Packard Enterprise's Spaceborne Computer-2 (SBC-2), a traditional rack server computer, as well as on embedded computers.

These embedded computers include the Snapdragon 855 processor, previously used in cell phones and cars, and the Myriad X processor, which has been used in terrestrial drones and low Earth orbit satellites.

Including ground tests using PPC-750 and Sabertooth processors – which are traditional spacecraft processors – these experiments validated more than 50 image processing, image analysis, and response scheduling AI software modules.

The experiments show these embedded commercial processors are very suitable for space-based remote sensing. This will make it much easier for other scientists and engineers to integrate the processors and AI algorithms into new missions.

The full results of their experiments were published in a series of three papers at the IEEE Geoscience and Remote Sensing Symposium.

Chien explains that while it is easiest to deploy AI algorithms from ground computers to larger, rack mounted servers like the SBC-2, satellites and rovers have less space and power, which means they would need to use smaller, low-power, embedded processors similar to the Snapdragon or Myriad units.

By processing the data onboard, these AI algorithms prevent important or urgent information from being buried within larger data transmissions. A researcher wouldn't have to downlink and process an entire transmission to see that a hurricane is intensifying or a harmful algal bloom has formed.

"A large image could have gigabytes of data, so it might take a day to get it to the ground and process it. But you don't need to process all that data to identify a wildfire. These algorithms pre-process data onboard so that researchers get the most important information first," said Chien.

These algorithms could be useful not only for Earth-observing instruments, but also for instruments observing other planets as well. The proposed Europa Lander mission, for example, could use Chien's algorithms to help search for life on the Jovian moon.

"There are several missions that are in concept development right now that could use this technology. They're still in the early phases of development, but these are missions that need the kind of onboard analysis, understanding, and response these algorithms enable," said Chien.

The team is also testing neural network models to interpret Mars satellite imagery. "Someday such a neural net could enable a satellite to detect a new Impact Ejecta, evidence of a meteorite impact, and alert other spacecraft or take follow-up images," says JPL Data Scientist Emily Dunkel. "Rovers could also use these processors with neural networks to determine where it is safe for the rover to drive," Dr. Dunkel adds.

"We used the CogniSat framework to deploy models to the Myriad X, reducing the effort to develop deep learning models for onboard use. This experience helps prove that this advanced hardware and software system is ready now for space missions," says Léonie Buckley, Senior Engineer at Ubotica.

As climate change continues to alter the world we live in, information systems like Chien's allow scientific instruments to be as dynamic as the Earth systems they observe.

"We don't often think about the fact that we're walking around with more computing power in our cell phones than supercomputers had forty years ago. It's an amazing world we live in, and we're trying to incorporate those advancements into NASA missions," said Chien.

The Spaceborne Computer 2 aboard the ISS, which allowed Chien to verify that his algorithms could not only run effectively on compact commercial processors, but also that those processors were fit for space-based applications. Credit: NASA

Parting the Clouds

A New Water Vapor Radar Takes Flight

As clouds rise through the atmosphere, they transport water vapor that condenses into liquid drops and releases large amounts of energy into burgeoning storm systems, turning mild weather events into violent squalls. Learning more about the relationship between water vapor and powerful storm systems would improve researchers' ability to forecast destructive weather events.

"We know that water vapor is a necessary fuel for severe storms, but exactly how water vapor contributes to the initiation and organization of severe storms remains unclear. Answering that question could really help us prepare for potential disasters more efficiently," said Matt Lebsock, a researcher at NASA's Jet Propulsion Laboratory (JPL).

Lebsock and fellow JPL researcher Ken Cooper are working on the Vapor In-cloud Profiling Radar (VIPR), a new instrument that would allow scientists to profile water vapor within the cloudy atmosphere. In other words, researchers would be able to measure the amount of water vapor in an active storm system as it forms, giving them unprecedented insight into how water vapor is distributed within storm systems and influences severe weather.

Researchers use a number of instruments to observe Earth's atmosphere and gather data for weather predictions, including tools like Lidar and passive infrared and microwave sensors. But these technologies are limited in their ability to measure water vapor as it circulates within churning, active weather systems.

"We can measure larger objects, like rain drops and snowflakes, but we can't quite observe the gases, like water vapor, within a storm system that bring so much energy to that system in the first place. It's a knowledge gap that makes it difficult to understand the small-scale details occurring within storms," said Lebsock.

In addition to studying water vapor in severe storms, VIPR will help measure water vapor within fair-weather clouds. Of particular interest are low altitude cumulus and stratocumulus clouds within the Planetary Boundary Layer (PBL). The PBL, which is the lowest portion of the atmosphere, interacts strongly with Earth's surface and is a top focus area identified in the 2017 National Academies Decadal Survey for Earth Science.

A key uncertainty in projections of climate change relate to how these clouds within the PBL might change in the future. Through its measurements of in-cloud water vapor profiles, VIPR will help researchers answer these questions.

To gather data on water vapor, VIPR transmits energy at very high microwave frequencies sensitive to water vapor concentration. These frequencies, near 170 GHz, are almost 100 times higher than those used for conventional weather radar, which introduced challenges in the development of the instrument.

VIPR takes advantage of several technology developments to bring high frequency microwave radar observations to the skies and, one day, even to space. In particular, VIPR's low-weight, high-power transmitter makes it possible to create instrumentation both fit for flight and powerful enough to observe absorption of radiation from water vapor molecules within active storms.

"When we first developed power-combined millimeter-wave Schottky diode frequency-multipliers at JPL, they achieved record performance by operating continuously at several hundred milliwatts. That may not seem like much, but this marked a huge development in our ability to build radars at an ultrahigh frequency," said Cooper.

Using this transmitter, the VIPR team assembled a prototype instrument and performed airborne tests onboard a small, unpressurized Twin Otter airplane in 2019 and 2020. The successful test flights proved their instrument concept was feasible, and they began upgrading the instrument for routine science measurements in different aircraft.

"We adapted VIPR to fly onboard a different, larger aircraft alongside a suite of other instruments," said Lebsock. Specifically, VIPR flew on NASA's P-3B Orion alongside the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) project.

In the future, VIPR could measure water vapor within winter storms, providing scientists with new insights into how this energizes storm systems and potentially makes them more destructive.

"We're very grateful to the IMPACTS team for letting us hitch a ride on their research flight. As VIPR continues to develop, we hope its gathered data will one day help them in their mission to learn more about winter storms," said Cooper.

VIPR graduated from ESTO's ACT and IIP programs before entering the Airborne Instrument Technology Transition (AITT) program, which matures measurement concepts like VIPR into instruments that are ready to be used in scientific airborne campaigns, such as IMPACTS.

Cooper and Lebsock have high hopes to one day integrate their instrument onboard a space-based platform and study storm systems across the globe. But for now, their goal is to use VIPR's IMPACTS flight to demonstrate their instrument is ready for NASA airborne field campaigns.

"A vantage point from space is hard to beat, but there's a lot of excellent science to be done using airborne platforms. VIPR could be an excellent addition to our current instrument capabilities," said Lebsock.

« Ken Cooper sits beside VIPR after its installation on NASA's P-3B Orion research aircraft. Credit: Ken Cooper, NASA

Spotting Disaster Early

The Ground Station Observation Network Aims to Speed the Time from Observation to Response

In the blink of an eye, floods, fires and fierce storms can lay waste to entire communities. NASA satellite data can help scientists predict these events with greater accuracy and even aid rescuers responding to disasters.

"When there's an urgent need for NASA data, how do we receive, process, and disseminate that data in the most efficient way possible? That's one of the questions we've been asking ourselves," said Louis Nguyen, a research engineer at NASA's Langley Research Center (LaRC).

Nguyen and his colleagues at LaRC developed a prototype software program that helps reduce data latency – the amount of time it takes data gathered by satellites and the derived data products to reach stakeholders back on Earth.

Whereas current downlinking and processing can take as long as three hours, Nguyen's Ground Station Observation Network (GSON) can deliver complete data packages in under 25 minutes.

Through GSON, stakeholders can schedule, coordinate, reserve, receive, and process low-latency, direct broadcast data from commercial receiving stations maintained by Amazon. The flexible data pipeline features a user-friendly interface making it easier for stakeholders to secure direct broadcast data from Earth-monitoring instruments in low Earth orbit.

GSON will become a critical component of NASA's New Observing Strategies (NOS) initiative, a push to unite dispersed sensors into a single observational tool using advanced information systems. In 2021, GSON made significant contributions to two NOS testbed demonstrations, showcasing the value NOS technologies will have for gathering future Earth measurements.

"During flood and wildfire simulations, we successfully used GSON to acquire satellite data into larger emergency data packages that would be available to first responders trying to mitigate these disasters," said Nguyen.

GSON meets NASA's Open Source Science requirements and will be freely available to the public from the NASA Technology Transfer Program.

"This makes NASA satellite data more accessible to a diverse range of customers, from professional researchers and citizen scientists to emergency first responders coping with a crisis," said Nguyen.

Earth-orbiting satellites must be within range of a receiving ground station in order to relay their data back to Earth. Depending on a satellite's orbit and the amount of data it needs to share, it may take hours before it can link to an available ground station.

"This latency is problematic for emergency applications. Imagine you're dealing with a rapidly changing event, such as a flood. By the time you get data that might help you understand the situation better, the landscape may have already changed significantly," said Nguyen.

Amazon Web Services maintains a global network of ground stations capable of receiving, processing, and disseminating NASA data 24/7. But it lacks a unified information system NASA's diverse user community can use to request specific data sets from various instruments and to customize with workflows tailored to their unique purposes.

"Depending on what a user wants to do with their requested data, they may need a data pipeline flexible enough to accommodate custom processing procedures. That type of program is critical for applying remote-sensing data sets to disaster mitigation," said Nguyen.

Nguyen created the Ground Station Observation Network to serve that role, giving NASA customers the benefits of global coverage with the flexibility and security of a private ground station. GSON provides efficient high-speed processing capabilities for creating parallel-process workflows. In addition, GSON allows users to attach custom notification and scripting programs directly into the system.

"It's user-friendly and tailored to generate science products faster. Stakeholders can also generate follow-on processing to further refine data products. We were careful to ensure GSON responded to the unique needs of NASA's data user community," said Nguyen.

For example, if a user wanted data describing a wildfire, that user could specify the satellite and instrument from which they'd like to receive data, reserve satellite contact with an Amazon ground station, and even set specific parameters for their desired data set through Nguyen's GSON portal. When that satellite passes within range of a ground station, it will automatically downlink and process the custom data package before sharing it with the user.

"The data goes straight from the ground station into the cloud, where it's processed according to the user's specifications. The user can then access their finished data product remotely from anywhere in the world with an internet connection. It sounds like a lot, but the whole process can take less than half an hour," said Nguyen.

Moving forward, Nguyen and his team plan on fine-tuning the GSON by participating in more NOS demonstrations and collaborating with other government agencies. Pioneering pathways for superior data acquisition using GSON will only make it a more useful tool for communities and researchers with urgent Earth data needs.

"NASA data has a critical role to play in emergency response and streamlined data acquisition, and the Ground Station Observation Network will help share NASA science more efficiently," said Nguyen.

Sounding the Atmosphere

A Miniature Microwave Limb Sounder Sets its Sights on Trace Gas Measurements

A new NASA instrument will help researchers study atmospheric chemistry in Earth's stratosphere, paving the way for future insights into complex chemical reactions and air motions that impact the ozone layer, as well as climate, air quality, and even aspects of weather patterns.

The instrument, "Continuity Microwave Limb Sounder" (C-MLS), is a compact space-based remote sensor that views the atmosphere edge-on (a process known as "Limb sounding"), and measures the tiny, naturally-emitted microwave signatures emitted by molecules of atmospheric trace gases. With that information, scientists can determine how a wide variety of minor trace gases are distributed around the world, observe how those trace gases are transported throughout the atmosphere, and study how those gases interact with each other, as well as with cloud and aerosol particles.

NASA already has a Microwave Limb Sounder instrument (MLS) in low-Earth-orbit aboard the Aura satellite, launched in 2004. But C-MLS features a number of significant improvements. It can detect nearly all the molecules visible to Aura MLS while observing only two spectral regions – 320-360 GHz and 620-665 GHz – compared to Aura MLS's five. This, along with the adoption of digital signal processing technologies, reduces power consumption and a enables dramatic reduction in size and weight.

By viewing the atmosphere at an angle, limb sounding instruments obtain measurements with better vertical resolution when compared to instruments that observe the atmosphere vertically – also known as "nadir" sensors. Additionally, because measurements from limb sounders transect hundreds of kilometers of atmosphere, they can detect signals from many more molecules compared nadir sounders. This provides a stronger signal for tenuous trace gases that play an important role in atmospheric chemistry.

Aura MLS weighs nearly 500 kilograms and consumes more than 500 watts of electricity, while C-MLS will weigh only 60 kilograms and consume just 80 watts of electricity. The lighter C-MLS instrument will help maintain a stratospheric composition record that began in the early 1990s for future generations of scientists.

For perspective, the microwave limb sounder onboard Aura relies on nearly 30 spectrometers each about the size of a brick, while C-MLS can accomplish nearly all the same observations with superior spectral resolution and bandwidth using only ten small chips that sit on circuit boards, each of which are the size of a credit card.

"Technology has advanced to the point where you could have a computer, a radio, and an analogue amplifier on one square of silicon," explained Nathaniel Livesey, an atmospheric scientist at NASA's Jet Propulsion Laboratory and the lead scientist for both Aura's Microwave Limb Sounder instrument and C-MLS. "This is the kind of technology that's inside modern cell phones. We're capitalizing upon of these advances by putting more and more of our subsystems inside custom chips."

Traditionally, MLS instruments required a lot of energy-hungry hardware. "For the receiver and spectrometer electronics, we're going from something the size of a small car to something the size of a carry-on bag, without sacrificing performance," said Livesey. Smaller instruments are easier to manufacture and send into space, meaning C-MLS makes it less difficult for researchers to send new microwave limb sounders into orbit.

C-MLS will be especially useful for monitoring Earth's Ozone Layer, a thin band of ozone gas in the stratosphere that shields Earth from the Sun's most powerful UV rays. Mere trace amounts of certain gases containing chlorine can destroy large amounts of ozone, most notably in the Antarctic "ozone holes" which have formed each southern Winter and Spring since the 1980s.

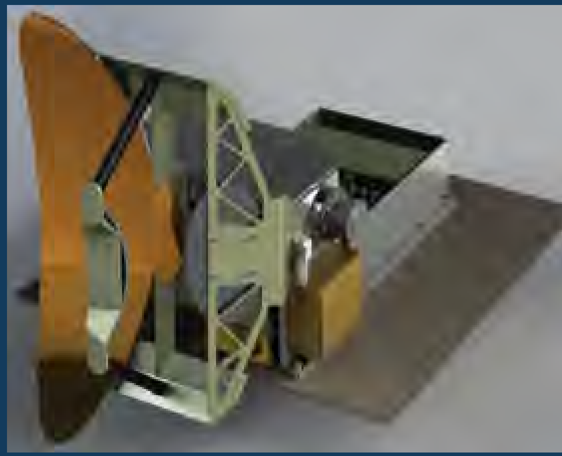
The Montreal Protocol is the first internationally accepted agreement to phase-out the production of ozone-depleting substances that entered into force in 1989. While ozone is recovering as expected in some regions of the atmosphere, there's a large amount of variability from year to year in other regions, which makes it difficult to discern just how well the ozone layer is recovering in other regions, notably over the Arctic.

"Indeed, ozone is still going down in some regions where we would have hoped to at least see a flattening off by now," said Livesey. "What we're seeing is within, but close to the edge of, the range predicted by models. We need measurements from sensors like C-MLS to tell us why ozone is behaving this way, and to ensure our understanding is correct."

C-MLS will also observe water vapor in the stratosphere, an important climate variable. Data from Aura MLS allowed scientists to determine that the January 2022 eruption of the Hunga Tonga-Hunga Ha`apai volcano lofted so much water vapor to high altitudes that stratospheric humidity increased by 10%.

Livesey said C-MLS could contribute to future NASA missions dedicated to observing atmospheric chemistry. NASA's Earth Venture and Earth System Explorer Programs, in particular, are ideal venues for launching and operating a mission with an instrument like C-MLS.

A sketch of the C-MLS instrument. Credit: Nathaniel Livesey, JPL



Monitoring Water Quality

New NASA Software Aims to Protect Aquaculture in the Chesapeake Bay

Excess nutrients and pollutants washed off of land by rainstorms can degrade water quality and harm marine life and humans. Identifying these problems before they can affect us is a constant challenge for water resource managers.

NASA, NOAA, and the Maryland Department of the Environment (MDE) are teaming up to create a software program to help identify impaired water quality more easily. The software is being designed to aid resource managers monitoring the Chesapeake Bay, which is home to a vibrant aquaculture industry that contributes more than $9 million annually to Maryland's state economy, according to the Chesapeake Bay Foundation.

This collaboration between federal and state agencies – which saw an opportunity to leverage NASA sensors mounted to MDE boats and a US Coast Guard tower – begins a complex software development process that includes collecting in-situ observations for training and verifying machine learning algorithms that will ultimately be used to identify areas of poor water quality in satellite images.

Though still in the early stages of development, the research team has already reached several important milestones. In particular, they demonstrated that their software is able to successfully train machine learning algorithms to identify precursors to poor water quality in satellite images over the Chesapeake Bay collected by NASA satellite MODIS-Aqua and the Sentinel 3 OLCI satellite, which is managed by the European Space Agency.

This software prepares scientists to maximize the utility of future missions – such as NASA's upcoming Surface Biology and Geology (SBG) and Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) missions – and to help coastal communities that depend on pollution-free seas for their livelihoods.

"Maryland and Virginia have decades of observational data, making the Chesapeake Bay the perfect place to develop and train our algorithms to find patterns too subtle for human eyes to detect on their own," said Stephanie Schollaert Uz, project principal investigator and Applied Sciences Manager at NASA Goddard Space Flight Center.

Schollaert Uz explains that as climate change leads to wetter, more-energetic storms, a larger amount of nutrients, sediments, and pollutants like raw sewage will find their way from urban environments into the sea. The excess run-off not only jeopardizes the health of aquatic ecosystems, but also the health of human beings.

"For example, sewage leaks or spills can contaminate an entire crop of oysters, and if the problem goes undetected, people can get sick," said Schollaert Uz.

Resource managers with the Maryland Department of the Environment work tirelessly to ensure the Chesapeake Bay is safe for aquaculture and recreation. But with hundreds of test sites to check each month, it's difficult to find every instance of polluted water before it can endanger people and the environment.

NASA satellites, with their broad coverage and multiple observations within a month, could be an excellent tool for augmenting state water quality monitoring programs. But many pollutants don't emit an optical signature that can be identified by satellite sensors, which use light to identify sediments, phytoplankton pigments, and dissolved organics. Instead, machine learning algorithms must detect secondary – or, "proxy" – patterns indicative of invisible pollutants.

Put another way, astronomers may not be able to observe a distant planet directly, but the orbits of other planets nearby might suggest this hidden planet is there none the less.

Troy Ames, project co-Investigator and Computer Engineer at NASA's Goddard Space Flight Center, explains that their program is composed of several key components to train machine learning algorithms using three-dimensional data cubes and look for evidence of poor water quality.

These components include encoder modules for extracting important information from raw data sets, a fusion module to aggregate that information into a discernible pattern, a temporal module to detail the evolution of information over time, and decoder modules to translate that information into water quality indicators.

"This facilitates both training and testing, because you can actually combine components in different configurations based on indicators," said Ames.

COVID-19 made it difficult for Schollaert Uz and her team to complete the in-person fieldwork and lab studies necessary for training their algorithms to identify run-off pollutants like sewage in satellite imagery. But they were able to use model output from the Virginia Institute of Marine Sciences Chesapeake Bay Environmental Forecast System to train machine learning techniques that assimilate satellite data to identify precursors to hypoxia such as areas of low oxygen that can be devastating to aquatic ecosystems.

"I can't emphasize enough how difficult it is to connect optical satellite imagery with hypoxia. Hypoxia happens at depth, not near the surface. This is a really complicated problem that regularly negatively impacts water quality," said Schollaert Uz.

To develop their project further, Schollaert Uz and her colleagues intend to bolster their current machine learning method with environmental information from NOAA and further field observations, with the ultimate goal of exploiting upcoming hyperspectral satellite data in near-real time for Chesapeake Bay resource managers.

"NASA maintains an incredible collection of Earth science data. We want to help people access and apply that data to solve real-world problems," said Schollaert Uz.

A New Market for Earth Observations

A Next Generation Radar Receiver Finds Commercial Opportunities

An ESTO-funded radar receiver may soon find its way into low Earth orbit aboard a commercial satellite, paving the way for future science missions powered by cooperation between NASA and private industry.

Developed by a team of researchers at the University of Michigan, the "Next Generation Bistatic Radar Receiver (NGRx)" is the first such receiver to measure both co-polar and cross-polar scattering signals, allowing researchers to study areas with heavy vegetation more accurately. Muon Space, an aerospace company based in California, plans to use NGRx to study Earth systems like surface topography and soil moisture using a constellation of SmallSats.

"We're building out what will eventually be a constellation of more than 30 satellites. The first two satellites will be going up next year, and one of those is going to be hosting the NGRx receivers," said Jonny Dyer, Muon Space's co-founder and CEO.

Dyer explains that his company wants to provide Earth scientists with comprehensive data describing things like severe weather, surface windspeed, and other systems that could help researchers better understand Earth's changing climate.

By launching its own space-based remote sensors, said Dyer, Muon Space dramatically reduces the cost of producing critical Earth science data products. Researchers and organizations only pay for mission-specific data they need, rather than having to fund and manage complete space development programs.

In the near future, NGRx may become an important component of Muon Space's instrument fleet. Muon Space's MuSat-2, scheduled to launch in 2023, will validate an NGRx prototype for spaceflight.

"We're very interested in adopting this technology and pushing it forward, both from a technology perspective and a product perspective," said Dyer.

Chris Ruf, who leads the NGRx research team at the University of Michigan and served alongside Dyer on a recent National Academies study, is excited to see a private company use NGRx to address pressing science needs.

"I'm totally psyched that this is happening. Private industry is jumping on this thing, and they think that there's a future business case for this instrument. I think it's great," he said.

In addition to Muon Space, NGRx also found a home with the New Zealand Space Agency, which currently flies an NGRx prototype onboard a domestic aircraft. That instrument, which transmitted its first data in September 2022, provides Ruf and his team at the University of Michigan with science data describing ocean surface windspeed.

"It's a domestic plane, so it flies 8-10 times a day, these little 60-minute hops between cities in New Zealand, and every time it's in the air the receiver automatically turns on and starts taking data. They drilled holes in the plane and installed antennas for us and everything, which was pretty amazing," said Ruf.

NASA has a long history of introducing groundbreaking innovations to the world. From memory foam to insulin pumps, NASA regularly contributes industry-changing technologies that revolutionize the kinds of research scientists can perform and the types of products companies can bring to market.

"The fact that ESTO proves out these measurement approaches – the technology and the instrument, the science that you can actually derive, the products from that instrument – is a huge enabler for companies like ours, because then we can adopt that technology and then scale them up commercially," said Dyer.

A Muon small satellite at the company's headquarters in Mountain View, California. An ESTO-funded radar receiver will help Muon SmallSats observe everything from severe weather to surface windspeed. Credit: Muon Space

FireSense

Bringing Technology Solutions to Wildfire Prevention and Response

ESTO recently launched the FireSense Technology program, paving the way for future air- and space-based remote sensors dedicated to managing wildfires.

Led by Michael Seablom, ESTO's Senior Strategist and FireSense Technology program manager, the program will develop new sensors and information systems for detecting pre-fire conditions that could lead to a wildfire, observing wildfires in real-time, and monitoring post-fire environments to better understand how wildfires impact other Earth systems.

FireSense Technology is only one component of NASA's Wildland FireSense Project, which leverages NASA resources agency-wide to prevent and study wildfires. The broader program encompasses the Earth Science Division's Research and Analysis and Applied Sciences programs as well as the Aeronautics Research, and Space Technology Mission Directorates, which contribute significant resources to this initiative.

NASA's Wildland FireSense Project comes at a time when the United States and countries around the world find themselves struggling to combat increasingly-severe wildfires. According to NOAA, wildfires in the U.S. caused more than $11.2 billion in damage between 2021 and 2022.

"NASA has looked at wildfires in the past, but this is taking it to an entirely new level. This has multi-mission support and is a priority at the very top of the agency," said Seablom.

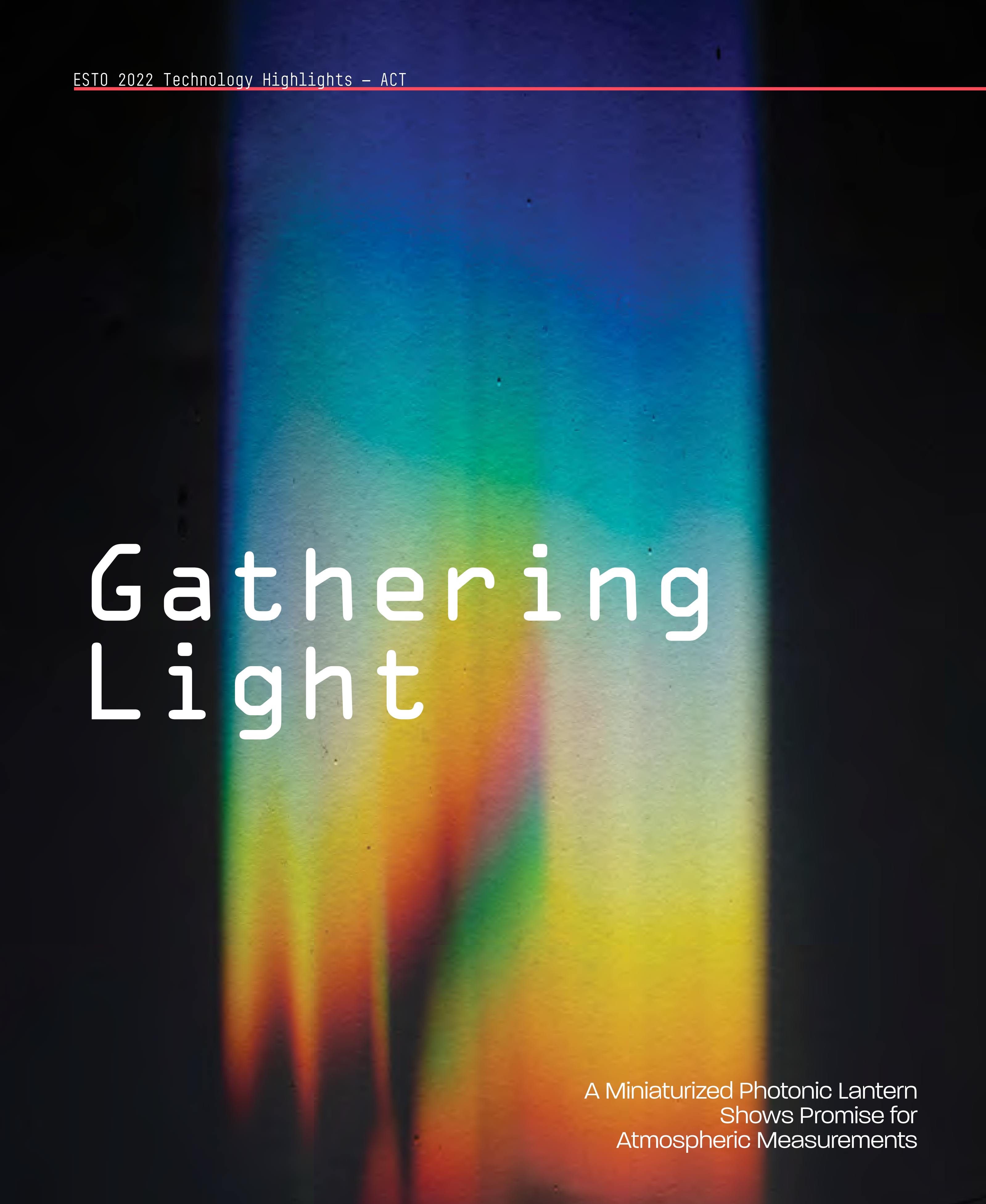
FireSense will give first responders and community leaders new tools for preventing wildfires and coping with fire-changed environments. Landslides, for example, are far more common after a wildfire, and communities miles away from an active blaze could suffer from increased air pollution.

"To address those issues intelligently requires the right data, the right modeling, and the right information systems. All of these are part of the FireSense initiative - to manage the fire before the fire occurs and the post-fire environment. It's a whole different set of problems," said Seablom.

Solving those problems will be an immense challenge, even for an organization with an accomplished history of problem-solving. To succeed, Seablom said, will require proper coordination with stakeholders such as firefighters and other first responders at the local, state, and national levels during the innovation process.

FireSense Technology already released its first call for proposals for innovative new technologies to confront wildfires and environmental changes caused by wildfires. More information about this solicitation can be found here.

Firefighters suit up to contain Oregon's Rum Creek Fire. FireSense Tech will leverage NASA technology to help communities combat wildfires more effectively. Credit: Robert Hyatt, NOAA



Gathering Light

A Miniaturized Photonic Lantern Shows Promise for Atmospheric Measurements

A new fiber optic instrument component may help researchers develop smaller telescopes, improved lidar instruments, and other advanced technologies for observing dynamic Earth systems.

Developed by researchers at the University of Central Florida (UCF), NASA's Langley Research Center, and the University of Sydney (Australia), the component – a novel photonic lantern – is designed to channel incident light along bundles of optic cables towards a detector array, which would then analyze the light for information about atmospheric features like aerosols and trace gases.

By tracking aerosols as they move within Earth's atmosphere, scientists can learn more about windspeed and weather patterns.

While photonic lanterns – tiny devices made of fiber optic cables about 3 centimeters long and 2 millimeters in diameter – already appear frequently in fiber communication experiments, they're completely absent in satellites performing science missions.

Traditional photonic lanterns lose about 20% of incident light while channeling it to a detector. NASA's new photonic lanterns, on the other hand, feature a unique refractive index that guides all but 4% of incident light to a detector.

"We are using fibers with very specific refractive index profiles to make these photonic lantern devices, and also we are using capillaries with specific geometries and a unique refractive index profile," explained Rodrigo Amezcua Correa, Professor of Optics and Photonics at UCF's College of Optics and Photonics (CREOL) and principal investigator for NASA's photonic lantern project.

A refractive index describes how light bends as it travels through optical cables and the glass capillaries that connect those cables to instrument sensors. Carefully controlling that index is critical for ensuring incident light remains intact as it travels from an instrument's aperture, such as a telescope lens, to its detectors.

With 98% efficiency, Correa's photonic lanterns are the most efficient yet developed. This improvement could greatly enhance lidar instruments, which use collected incident light to study a wide variety of complex Earth systems, including aerosols and surface windspeed.

"We decided what we needed to do was create a photonic lantern to capture more light, and then split it into several single-mode signals, which allows for determination of Doppler phase shifts to derive phenomena like wind speeds. That's where we started discussing the applications for lidar," said Correa.

Correa's custom fiber optic cables also serve as a kind of filter. Different cables transport different spectra of light, and large, multimode light signals containing numerous spectra of light break apart into smaller, single-mode signals as they pass through this new photonic lantern.

By transforming multimode signals into single-mode signals, Correa's photonic lanterns reduce noise interference and could help make lidar more efficient.

"What we now have is a multi-mode photonic lantern that splits into a series of internal mode fibers, which means we capture a lot more light than traditionally captured with a conventional coherent lidar," said Correa.

With three photonic lantern prototypes completed, Correa and his team plan to demonstrate their new technology in their UCF laboratory. Next, colleagues at NASA Langley will study the photonic lanterns operating within a full lidar system.

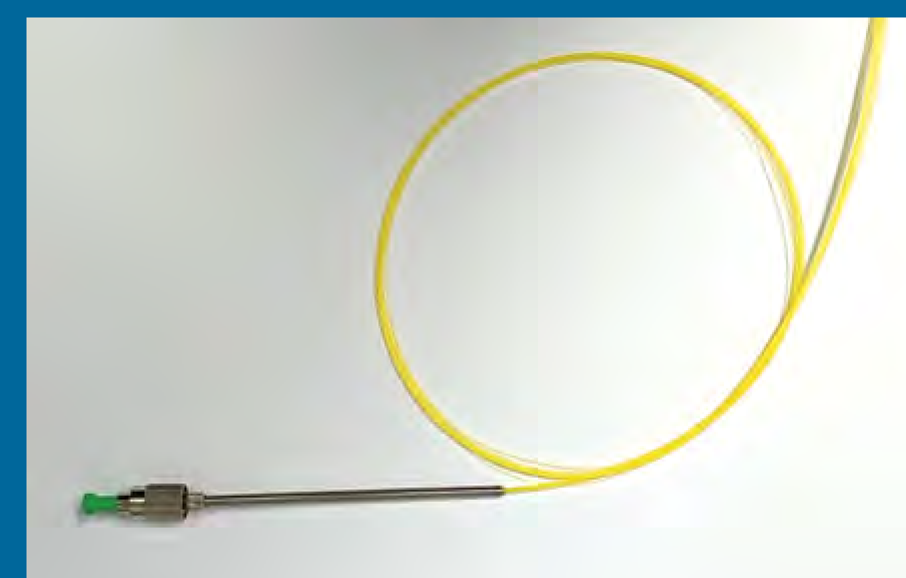
At UCF's CREOL laboratory, Correa teaches undergraduate and graduate students how to craft the special fibers needed for these new photonic lanterns.

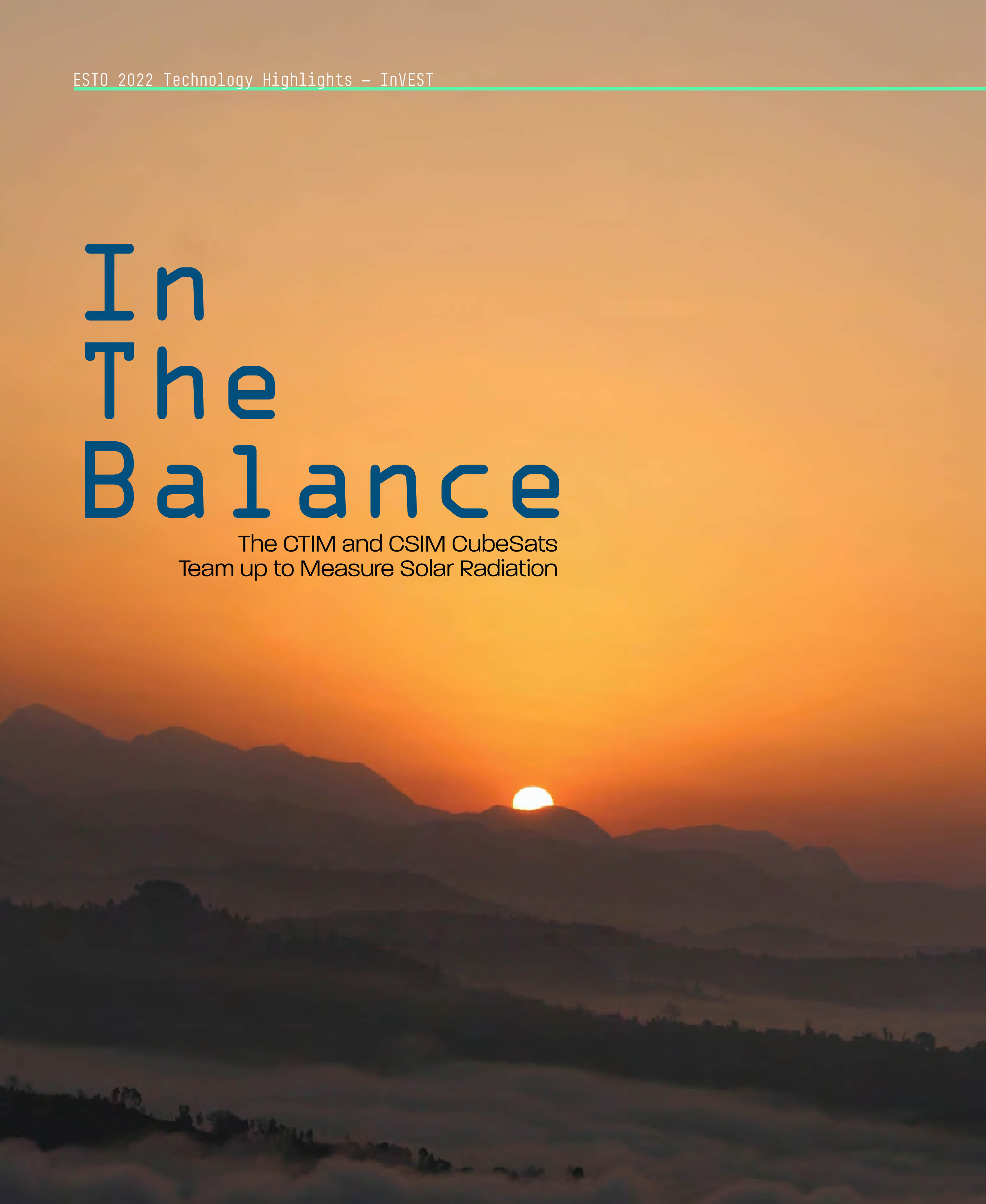
"There is a lot of manual work going into making the devices. You need a lot of experience. So, we spend a lot of time learning how to actually make these devices. We are looking for ways to improve that process," said Correa.

Once they validate their photonic lantern prototypes, Correa and his team will begin preparing their instrument component for ground and aircraft validation.

"The photonic lantern will be targeted to the specific instrument. It will depend on the wavelength of an operation, the type of lidar receiver that you're working with, and other factors, but we can essentially create custom photonic lanterns for different instruments. This is a new, exciting capability," said Correa.

A photonic lantern developed by researchers at the University of Central Florida, NASA Langley, and the University of Sydney. This component will help improve lidar instruments, which use incident light to study Earth systems like surface windspeed. Credit: Rodrigo Amezcua, University of Central Florida





In The Balance

The CTIM and CSIM CubeSats Team up to Measure Solar Radiation

A pair of NASA projects will help researchers better understand the relationship between solar radiation and Earth systems like severe weather and climate change.

Two small instruments are powering big scientific insights by measuring and analyzing all Earth-directed energy coming from the sun, which will allow scientists to understand how that energy influences our planet's severe weather, climate change, and other global forces.

Developed by researchers at the University of Colorado's Laboratory for Atmospheric and Space Physics (LASP), the Compact Total Irradiance Monitor (CTIM) and Compact Spectral Irradiance Monitor (CSIM) are among the smallest instruments ever dispatched to study solar energy and its impact on Earth systems; each instrument is about the size of a large shoe box.

CTIM, which launched earlier this year, will help scientists determine if small satellites could be as effective at measuring total solar irradiance as larger instruments, such as the Total Irradiance Monitor (TIM) instrument used aboard the completed SORCE mission and the ongoing TSIS-1 mission on the International Space Station.

CSIM, which launched in 2018, helped scientists observe individual spectra of solar radiation with less than 1% uncertainty – an unprecedented level of accuracy for a small satellite dedicated to observing solar spectral irradiance (SSI).

Together, the two CubeSats represent a significant advancement in our ability to understand the Earth Radiation Budget (ERB), or, the amount and types of energy Earth absorbs or reflects, as well as thermally emits, back into space.

"By far the dominant energy input to Earth's climate comes from the Sun," said Dave Harber, a senior researcher at LASP and principal investigator for CTIM. "It's a key input for predictive models forecasting how Earth's climate might change over time."

"It's very important, from the atmospheric chemistry point of view, to determine how much ultraviolet radiation, infrared radiation, and other wavelengths of radiation Earth receives, and how the amounts of each type of radiation changes over time," added Erik Richard, a Senior Researcher at LASP and principal investigator for CSIM.

Both instruments take advantage of a new carbon nanotube material—developed in partnership with NIST—that absorbs 99.995% of incoming light. This makes them uniquely well-suited for measuring total and spectral irradiance, respectively.

"It looks a bit like a very, very dark shag carpet. It was the blackest substance humans had ever manufactured when it was first created, and it continues to be an exceptionally useful material for observing TSI," said Harber.

Made of minuscule carbon nanotubes arranged vertically on a silicon wafer, the material absorbs nearly all light along the electromagnetic spectrum.

Using only about as much material as would fit on the face of quarter, CTIM can measure TSI, or, the gross sum of all sunlight that reaches Earth – about 1,361 watts per square meter at the top of Earth's atmosphere.

CSIM operates slightly differently: a precision aperture allows a measured amount of solar radiation to reach an internal prism, which breaks that solar radiation sample into individual wavelengths. Multiple radiation detectors, made of LASP's new carbon nanotube material, then measure how much of each wavelength is present in the sample.

In the future, NASA may merge CSIM and CTIM into a combined, compact satellite payload, allowing scientists to monitor both the total amount of solar energy reaching Earth and the individual spectral components making up that total with a small constellation of CubeSats.

"Right now, we're going through the data we collected with CSIM and exploring the possibility of developing a new design to merge it with the new CTIM instrument. That would be a really exciting development for solar irradiance studies," said Richard.

NASA's Compact Total Irradiance Monitor (CTIM) instrument, which will help researchers better understand how solar energy impacts innumerable Earth systems. Credit: Tim Hellickson, University of Colorado, Boulder

Technologies On Orbit

ESTO's InVEST program validates new technologies in the harsh environment of space. The program aims to reduce the overall risk of incorporating new technologies into future Earth science missions. Recent advancements in small, standardized satellites and low-cost access to space are rapidly transforming the way technologies are demonstrated and validated. Meaningful risk reduction for hardware components and information systems can be accomplished quickly for future flight instruments. Here are some recent highlights from the InVEST program:

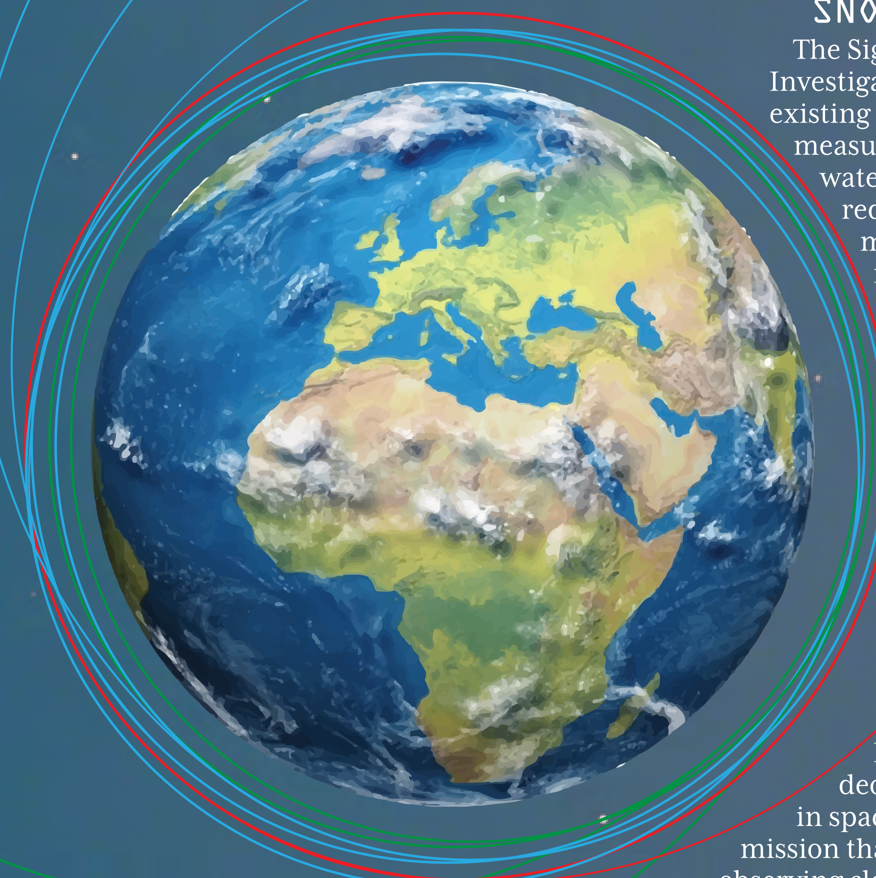
Launched in FY22

NACHOS 1&2

The Nanosat Chemistry Hyperspectral Observation System (NACHOS and NACHOS2) features an ultra-compact hyperspectral imager that pre-processes data in situ, targeting NO_2, SO_2, ozone, formaldehyde, and other gases with sufficient spectral resolution to confidently separate the trace gas signatures from the atmosphere. Launched February / July 2022.

CTIM

The 6U Compact Total Irradiance Monitor-Flight Demonstration (CTIM-FD) aims to measure Total Solar Irradiance with equal or better accuracy than previous missions in a much smaller envelope by utilizing Vertically Aligned Carbon Nanotube (VACANT). Launched July 2022.



Launching in FY23

HyTI

The Hyperspectral Thermal Imager (HyTI) aims to demonstrate high-spatial, spectral, and temporal resolution thermal infrared (TIR) imagery acquisition from low Earth orbit. Launching NET February 2023.

MURI

The Multiband Radiometer Imager is a thermal imaging radiometer boasting a 2x increase in resolution over previous instruments. Launching NET December 2022.

SNOOPI

The Signals of Opportunity P-band Investigation (SNOOPI) reuses signals from existing tele-communications satellites to measure root zone soil moisture and snow water equivalent. SNOOPI does not require a transmitter, making it much more cost effective and enabling measurements in all weather conditions day or night. Launching NET March 2023.

De-Orbited in FY22

HARP

The Hyper-Angular Rainbow Polarimeter (HARP) instrument deorbited in April 2022 after 777 days in space, successfully ending a two-year mission that pioneered new technologies for observing cloud and aerosol properties from space, which is crucial for learning more about Earth systems like air pollution and climate change.

Timeline of ESTO Launches

2013
COVE
IPEX
2014
2015
GRIFEX
2016
RAVAN
2017
IceCube
MIRATA
2018
RainCube
TEMPEST-D
CubeRRT
CSIM-FD
2019
HARP
CIRiS
2020
2021
2022
NACHOS 1&2
CTIM
MURI
2023
HyTI
SNOOPI
Beyond
ACMES
ARCSTONE
ARGOS

Student Spotlight

Students are vital to many technology development efforts. In FY22 alone, at least 119 students from 37 institutions were involved in active ESTO projects. Here are a few highlights from the past year.

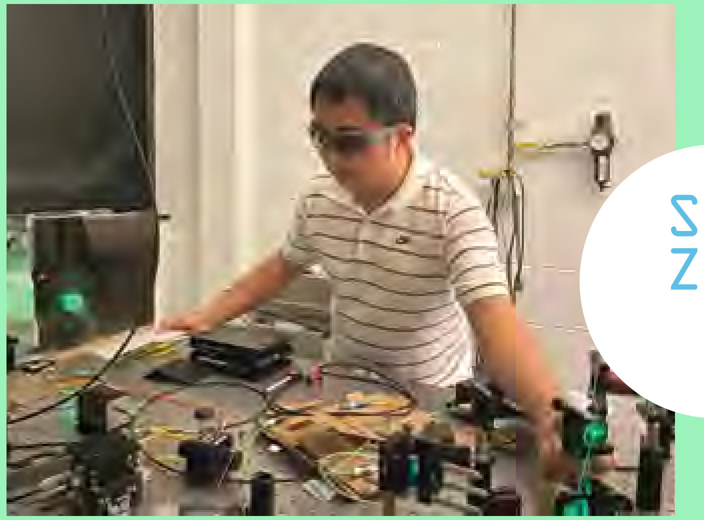
Hyemin Jung

Hyemin Jung, a Ph.D. student in electrical and computer engineering at The Ohio State University, is contributing to an ACT project that is developing a short-wave infrared avalanche photodiode capable of operating in space without large cryocoolers. Such a detector could support spaceborne lidar receivers that monitor greenhouse gases or provide high resolution topographic imaging. She is involved in device fabrication and epitaxial growth – repeatedly depositing atomic layers of material to create a single crystal that contains all the detector layers. Hyemin, an avid traveler, plans to graduate in 2025.

Adam Hines

For the last 4 years Adam Hines has been considering gravity. More specifically, the Ph.D. student of Aerospace Engineering at Texas A&M has been developing technologies for optomechanical accelerometers, compact laser interferometry devices that hold promise for improving the sensitivity and reliability of Earth gravity measurements. Adam's design, simulation, and characterization work on an optical resonator helped form the basis for a recently awarded IIP 2021 proposal led by his advisor, Dr. Felipe Guzman. Adam hopes to continue instrumentation research and development following his planned graduation in Fall 2022.

Shenyu Zhu



Shenyu Zhu, a Physics Ph.D. student at the Stevens Institute of Technology, is contributing to a new IIP project that is developing a lidar that takes advantage of quantum technologies to profile and characterize deep snowpack. With a background in optical engineering and machine learning, Shenyu is involved with work on nonlinear frequency-conversion single photon detection, a time-frequency mode sorting technique that could improve the backward scattered photon detection of deeper layers of the snowpack. During his graduate studies, Shenyu has also worked on computational imaging, especially non-line-of-sight imaging.

Hannah Tomio

Hannah Tomio is a research assistant in the MIT Space Telecommunications, Astronomy, and Radiation (STAR) Lab, where she is pursuing a Ph.D. in Aeronautics and Astronautics. This summer, Hannah applied her expertise in computer engineering and digital design to the CASALS project, an IIP award that is developing a wavelength-scanning space lidar with 3-D mapping capabilities. Hannah is also a 2021 NASA Space Technology Graduate Research Opportunities awardee and is helping to develop CLICK-A, a NASA-funded CubeSat that will demonstrate laser communications. Hannah is also a student of languages, including Japanese, French, Russian, and Swahili.

Taojun Wang

Taojun Wang, a Ph.D. student in Electrical and Computer Engineering at Purdue, is helping an AIST project develop a machine learning algorithmic framework and toolkit that could aid in the harmonization of data from various sources, time scales, and spatial scales. Her work focuses on multi-scale remote sensing data fusion, specifically, integrating the rich spectral information from multispectral/ hyperspectral imagery and high spatial resolution RGB images to detect fine details on the ground. Over the summer, Taojun collected data using integrated UAV and wheeled platforms and developed data processing software for orthophoto generation and feature extraction.

Leigha Capra

Leigha Capra, a mechanical engineering senior and undergraduate researcher with the Collective Design Lab at the Stevens Institute of Technology, is contributing to an AIST-funded New Observing Strategies Testbed (NOS-T) project to develop a distributed mission testbed. The project is utilizing MQTT network protocols to simulate communication between observing system components, and Leigha supports development of the testbed software to allow users to quickly adapt the framework to their unique mission needs. Leigha is also a member of The Stevens Institute of Technology women's fencing team and has notched over 100 career victories at Epee.

Josue Tapia-Tamayo

Josue Tapia-Tamayo is a Ph.D. candidate in systems engineering at The Stevens Institute of Technology and a graduate research assistant with the Collective Design Lab. His research develops computational tradespace analysis methods and tools for distributed spacecraft missions, and he contributes to the development of the AIST-funded Tradespace Analysis Tool for Constellations (TAT-C), focusing on integrated mission analysis using nature run data. In particular, his efforts investigate how to optimize constellation design to maximize the scientific value of Earth-observing systems, exploring responsive observing systems that could more rapidly detect and respond to hazardous events such as floods, wildfires, or strong convective storms.

Caleb Dobias & Keana Paredes

Two University of Central Florida students Caleb Dobias (Ph.D.) and Keana Paredes (senior undergraduate) are working with principal investigator Rodrigo Amezcua Correa on an ACT project to fabricate and test photonic lanterns (see page 28) for use in aerosol, trace gas, and wind atmospheric lidars. Caleb and Keana are part of a team at UCF's Center for Research and Education in Optics and Lasers (CREOL) that is aligning the benchtop lidar and characterizing the lanterns. "This work could help study the source, growth, and movement of atmospheric pollutants, and I find work that supports the health of the environment incredibly rewarding," said Caleb, who is in is third year of graduate studies. Keana plans to graduate in 2023 with a Photonic Science and Engineering degree and hopes to continue her studies at CREOL. When they're not stripping and splicing optical fibers, the two enjoy getting out of the lab – Keana frequents museums and flea markets, and Caleb likes live music and jazz.

Accelerating Minority Serving Institutions

MSI SPACE ACCELERATOR

ESTO ✦ STARBURST ✦ JPL ✦ MUREP

A first-of-its-kind NASA innovation competition, the Minority-Serving Institution (MSI) Space Accelerator, engaged a diverse group of scholars at minority-serving institutions in 2022 to advance the agency's goals for improving science missions and meeting critical needs in the areas of machine learning, artificial intelligence, and autonomous systems. The competition was a partnership between NASA's Science Mission Directorate, its Earth Science Technology Office, the Minority University Research Education Project (MUREP) within the agency's Office of STEM Engagement, NASA's Jet Propulsion Laboratory (JPL) in Southern California, and Starburst, a global aerospace accelerator company based in Los Angeles.

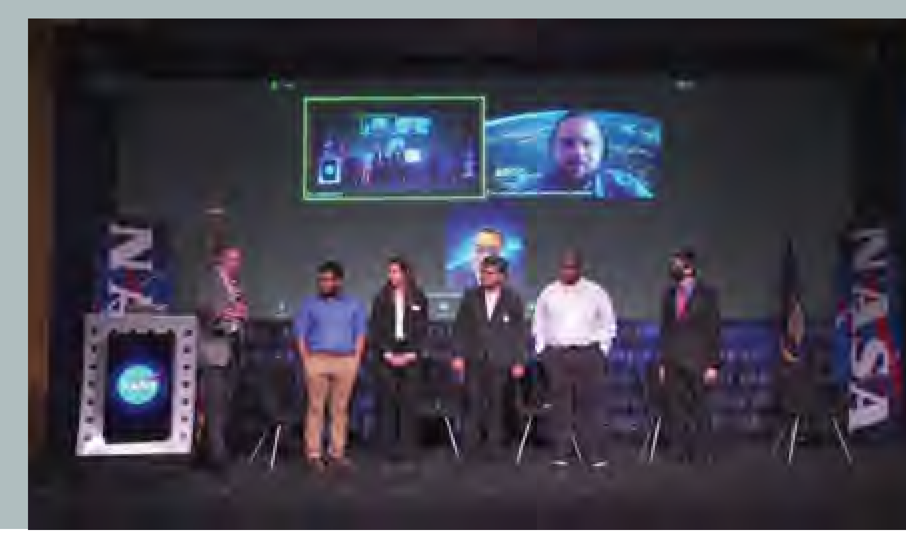
Three teams from minority-serving academic institutions were selected as awardees in June, and each received $50,000 in funding and were matched with mentors at JPL for summer training sessions. The teams also participated in a 10-week accelerator program operated by Starburst to help them prepare to commercialize their proposals by creating a business plan, refining their pitches, and building relationships within the field.

Selected by NASA reviewers from an initial round of applications, the winning proposals are as follows:

- **California State University, Northridge** (CSUN): Led by professors Kyle Dewey and Nhut Ho of the university's Autonomy Research Center for STEAHM, the CSUN team proposed a new programming language, Proteus, that is designed for writing aerospace software and can "serve as a common language between systems and software engineers," among other innovations, according to the proposal. The team has already received support from MUREP for this project and has collaborated with experts at JPL on a prototype.
- **Fayetteville State University** (FSU): The FSU team's proposal, called "Autonomous Systems with On-Demand Inference from Perception Pipelines," would help groups of multiple robots to work better together. For instance, it would seek to maximize science data from a rock scanned from various viewpoints on Mars. Led by computer science professor Sambit Bhattacharya, the team has already received several previous grants from NASA and JPL.
- **University of Massachusetts Boston**: Led by engineering professor Tomas Materdey, the UMASS Boston team is developing a system of autonomous drones, recharging stations, and sensor nodes "where every component has knowledge of what is happening elsewhere, so to adapt and adjust to the new situation," the group's proposal stated.

Opportunities for follow-on funding are anticipated, particularly through ESTO's Advanced Information Systems Technology program, which plans an open solicitation – with topics related to autonomy, artificial intelligence, and machine learning – in the summer of 2023.

For more on the MSI Space Accelerator, visit: https://nasa-space-accelerator.com



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