National Aeronautics and Space Administration

the earth observer

The Earth Observer. May - June 2013. Volume 25, Issue 3.

Editor's Corner

Steve Platnick
EOS Senior Project Scientist

Every Earth-observing mission that has ever flown began as an inspiring vision of what might be possible, followed by a long and challenging journey as the vision confronted reality—both technical and financial. As those who have been involved in developing missions and instruments can attest, it is a journey of many years. Of course some visions never make it to space, but the ones that do are typically based on demonstrated and mature technology.

In 1998, as the first missions of the Earth Observing System (EOS) began to launch, NASA established the Earth Science Technology Office (ESTO) as a testbed to develop technology that could be used for future missions and instruments. ESTO uses an end-to-end approach for demonstrating advanced and cost-effective technologies that help NASA fulfill its science objectives. To date, more than 37% of ESTO-funded technologies have been infused into Earth-observing spaceborne and airborne missions. Please turn to page 22 to read more about recent ESTO projects.

continued on page 2

These images of Paluweh volcano, in the Flores Sea, Indonesia, were obtained on April 29, 2013 by the Landsat Data Continuity Mission's (LDCM) Operational Land Imager (OLI) [*top*] and Thermal Infrared Sensor (TIRS) [*bottom*]. The image pair illustrates the value of having both OLI and TIRS on LDCM. Indeed, "the whole is greater than the sum of its parts." The OLI captures a high-resolution visible image of the plume showing the white cloud of ash drifting northwest over the darker forests and water. Adding the TIRS image allows us to "see" into the infrared and reveals a bright white "hot spot" over the volcano, surrounded by cooler ash clouds, and highlighting TIRS ability to detect very small changes in temperature over small distances—down to about 0.10 °C (0.18 °F). **Credit:** Robert Simmon, NASA's Earth Observatory, using data from the U.S. Geological Survey and NASA.

eos.nasa.gov

In This Issue

Reminder: To view newsletter images in color, visit: *eospso.nasa.gov/earth-observer-archive.*

As an example, the Soil Moisture Active–Passive (SMAP[1]) mission—the first planned "Decadal Survey[2]" mission—reaped benefits from ESTO's *observing system simulation experiments* (OSSEs) conducted under the Advanced Information Systems Technology Program.

[1] SMAP is scheduled to launch in late 2014.
[2] The National Research Council's 2007 Earth Science Decadal Survey—*Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (*www.nap.edu/catalog.php?record_id=13405*).

The OSSEs are leading to refinements in land surface models to reduce uncertainties in retrievals of key hydrologic parameters and make the best use of SMAP data. Be sure to read the update on SMAP's calibration/validation activities on page 32.

Of course, the journey doesn't end when the instruments are deployed in the field or in orbit—in fact, it's just beginning. NASA has made great strides in getting its unique measurement and product datasets into the hands of scientists, decision makers, policy makers, and the like. Doing so requires a committed partnership between data providers and end users. This is exactly the goal of NASA's Short-term Prediction Research and Transition (SPoRT) program. Established in 2002 to demonstrate the weather forecasting application of realtime EOS measurements, the SPoRT project has grown into an end-to-end research-to-operations activity focused on the use of advanced modeling and data assimilation techniques, nowcasting tools, and unique high-resolution multispectral data from satellites to improve short-term weather forecasts on regional and local scales. Beginning on page 4, we present the different NASA products and research capabilities that are being transitioned to end users.

We also continue our coverage of NASA's ongoing and upcoming missions and instruments. The Operation IceBridge mission has been an opportunity to test existing technologies on NASA aircraft, evaluate new satellite instrument concepts, and update observations of land and sea ice. There have been several campaigns conducted over the past few years, with the most recent having just concluded. The IceBridge team began measuring sea ice, mapping sub-ice bedrock, and gathering data on Greenland's glaciers in mid-March. Twenty-six science flights were flown out of Thule Air Base and Kangerlussuaq in Greenland, along with a short deployment in Fairbanks, AK. The data collected during ICEBridge expands upon the record that began with the Ice, Clouds, and Land Elevation Satellite (ICESat) in 2003, "bridging" the gap in satellite observations between ICESat (which ended in 2010) and the planned ICESat-2 mission (scheduled for launch in 2016).

In our last issue, we reported on the successful launch of the Landsat Data Continuity Mission (LDCM) on February 11. Three months later LDCM took its place in the Morning Constellation. The spacecraft performed its fourth and final ascent burn on April 12 and is now situated so that it obtains eight-day phasing with Landsat 7, and passes the Afternoon Constellation at a safe distance behind Aura. Its two instruments[3] appear to be in good working order and are already obtaining spectacular images—such as the image pair

[3] The LDCM instruments include the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS).

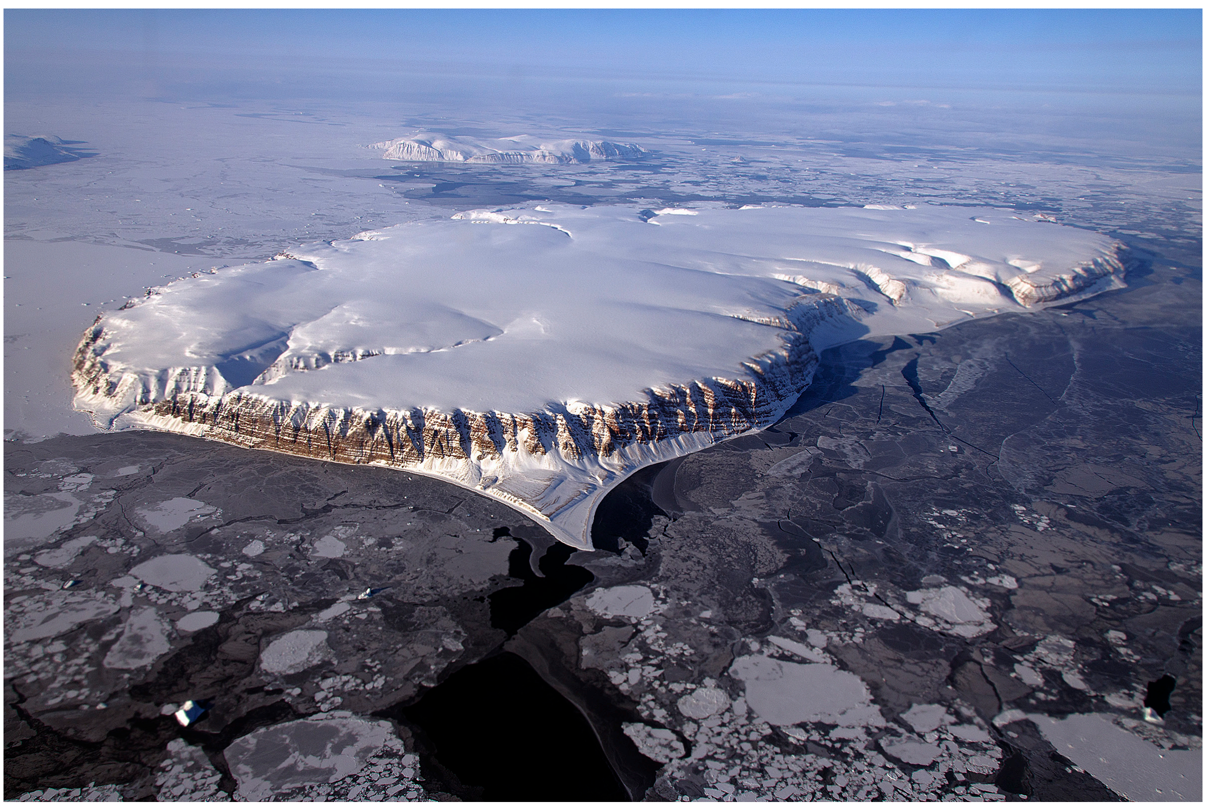
shown on page 1. On May 30, NASA officially passes control of LDCM over to the U.S. Geological Survey, and it is at that point that the satellite becomes known as Landsat 8.

Meanwhile, Landsat 5 personnel began the satellite's *Phase 2* exit activities with a deorbit burn successfully performed on April 17. The team plans to execute burns every week until the fuel runs out.

Previously, we reported on the Tropospheric Emissions: Monitoring of Pollution (TEMPO[4]) EV-I mission. On page 12 of this issue we have a report on the Cyclone Global Navigation Satellite System (CYGNSS) mission, selected through the EV-2 solicitation. Scheduled to launch in 2016, CYGNSS will employ an innovative design that will feature eight nanosatellites, launched from the same spacecraft, flying in close proximity to one another. This *constellation* of observatories will allow unprecedented temporal and spatial coverage of the core environment of developing tropical cyclones than current scatterometers can obtain. While improved hurricane forecasting is not CYGNSS mission's primary objective, it is hoped that hurricane prediction—in particular, hurricane intensity forecasts—will improve as a result of the data that the mission returns.

Finally, I am pleased to announce the redesign of the Earth Observing System Project Science Office (EOSPSO) website at *eospso.gsfc.nasa.gov*. The user interface has changed significantly which allows for more straightforward navigation through the site. To view this newsletter issue in color, or to access issues that date back to March-April 1999, click on *The Earth Observer Newsletter* menu option and click on the desired issue listed on the index page. An extended explanation of new features—*Announcing a New Look for the EOS Project Science Office Website*—appears on page 41 of this issue. We hope you enjoy the new site! ■

[4] TEMPO was chosen as an Earth Venture Instrument (EVI-1) mission. A report on TEMPO appears in the March–April 2013 issue [**Volume 25**, **Issue 2**, pp.10-15].



This image shows Saunders Island and Wolstenholme Fjord with Kap Atholl in the background observed during an IceBridge survey flight over Greenland. Sea ice coverage in the fjord ranges from thicker, white ice seen in the background, to thinner, *grease ice* and *leads* showing open ocean water in the foreground. **Credit:** NASA/**Michael Studinger**

Transitioning NASA Earth-observing Satellite Data to the Operational Weather Community

Gary Jedlovec, NASA's Marshall Space Flight Center, SPoRT Project Scientist, gary.jedlovec@nasa.gov

Established in 2002 to demonstrate the potential for using real-time EOS measurements in weather forecasting, the Short-term Prediction Research and Transition (SPoRT) project has grown into an end-to-end, research-to-operations activity focused on using advanced modeling and data assimilation techniques, nowcasting tools, and unique high-resolution multispectral data from satellites to improve short-term weather forecasts on regional and local scales.

Introduction

Beginning in 1999 with the launch of the Terra satellite, NASA embarked on the development of a comprehensive Earth Observing System (EOS) satellite fleet to measure the impact of human activities on Earth's geological, biological, and atmospheric processes. Scientists analyzing the vast amounts of data from the large suite of instruments flown by NASA over the last 15 years have made important revelations about the climate of the Earth and the complex nonlinear processes that govern its change. Equally important are the measurements these sensors take of smaller-scale and faster-changing atmospheric features, which govern faster-changing Earth system processes, such as weather.

Getting these unique measurements into the hands of decision makers in a timely fashion, however, presents a challenge that requires a committed partnership between data providers and end users. Without such cooperation new data, tools, and enhanced forecast techniques that are provided to the operational users, effectively fall to the bottom of a "valley of death," and never get successfully implemented or used. (The phase "valley of death" is a metaphor for the barriers and obstacles separating research results and operational applications.) The National Research Council (NRC) 2000[1] and 2003[2] reports indicate that successful transitions require understanding the importance and risks of transition, developing appropriate transition plans, providing adequate resources for the transitions, and implementing continuous communication and feedback between the research and operational communities.

Established in 2002 to demonstrate the potential for using these real-time EOS measurements in weather forecasting, the Short-term Prediction Research and Transition (SPoRT[3]) project has grown into an end-to-end, research-to-operations activity focused on using advanced modeling and data assimilation techniques, nowcasting tools, and unique high-resolution multispectral data from satellites to improve short-term weather forecasts on regional and local scales. While initially funded by NASA's Research and Analysis Program, SPoRT also supports the objectives of the Applied Science Program by demonstrating innovative uses and practical benefits of NASA-generated Earth science data, scientific knowledge, and research technology. SPoRT has developed and follows a conceptual transition of *research-to-operations* (R2O) model, which involves close collaboration with the end user and provides a "footbridge" over the valley of death. The transition of research data to the operational community better prepares forecasters for the use of new weather data, since NASA's instruments are often precursors to instruments flown by the National Oceanic and Atmospheric Administration (NOAA) on later operational weather satellites. This article describes this transition-to-operations model and the activities that contribute to its success.

Background

The concept of using NASA's EOS observations to improve weather forecasting dates back to the early 1990s; in particular it has been a priority for the Advanced Infrared Sounder Science Team from its inception. The deliberations most relevant to the development of SPoRT began in 2001, when Earth Science Division program managers from NASA Headquarters and NASA's Marshall Space Flight Center (MSFC) began discussing the possibility. Several key activities around that time facilitated the

[1] National Research Council, 2000: *From research to operations: Weather satellites and numerical weather prediction—Crossing the valley of death.* National Academy Press, Washington, DC, ISBN: 0-309-56291-0, 96 pp.

[2] National Research Council, 2003: *Satellite observations of the Earth's environment: Accelerating the transition of research to operations*. National Academy Press, Washington, DC, ISBN: 0-309-52462-8, 182 pp.

[3] The SPoRT website is *weather.msfc.nasa.gov/sport*.

concept of a regional center to transition EOS data to the operational weather community. NASA had recently launched several of its new EOS satellites to make global observations of the Earth-atmosphere-ocean system to better understand the Earth's climate and how it might be changing. Additionally, numerous low-cost direct-broadcast ground receiving stations were being installed across the country to make real-time data from new EOS instruments—such as the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard Terra and Aqua, and the Atmospheric Infrared Sounder (AIRS) and Advanced Microwave Scanning Radiometer for EOS (AMSR-E) onboard Aqua—available to the user community. At that time, NASA was also establishing a collaborative partnership with the Department of Defense and NOAA to create the Joint Center for Satellite Data Assimilation (JCSDA) to focus on assimilating NASA satellite data into global weather models to improve medium-range (two-to-seven-day) weather forecasts. The SPoRT mission to focus on improving short-term weather forecasts on regional and local scales nicely complemented that of the JCSDA.

The transition of NASA research and experimental data to the operational weather community for evaluation and use requires a committed partnership between data providers and end users. SPoRT bridges the gap between these two groups to make unique data and products developed by the research community available to the operational weather community.

At the same time, NOAA's National Weather Service (NWS) was planning to relocate and open a new weather forecast office in Huntsville, AL, to be collocated with NASA scientists from MSFC's Earth Science Office, and the atmospheric research and educational components of the University of Alabama. The potential synergy between the three organizations working together to advance weather diagnostics, nowcasting, and forecasting techniques as a result of the EOS program was electrifying! MSFC scientists developed a proposal to use EOS observations from the direct-broadcast data streams across the country to do just that. NASA funded the initial and subsequent follow-on proposal to facilitate the use of EOS data in NWS forecast offices to improve short-term weather prediction.

The SPoRT program has undergone significant development since its inception in 2001. The program is currently in the third phase of a multiphase project. Initial development focused on working closely with NWS staff to understand how they do business, identifying forecast problems and matching them to unique NASA observational and modeling capabilities, and establishing a successful paradigm for the transition of research capabilities to the operational weather environment. Early successes with transitioning MODIS data (February 2003) and local ground-based total-lightning data (April 2003) into AWIPS[4], and demonstrating the impact NASA satellite data could have on regional modeling activities provided encouragement for the second phase of the project. During the second phase, SPoRT expanded its interactions with end users and their forecast problems, and assessed the impact NASA observations had on Weather Service operations across the country. SPoRT is now in a third phase, where it has partnered with NOAA's proving grounds and test beds to demonstrate the utility of future NOAA operational sensors. SPoRT also provides the tools and technology to transition additional data and research capabilities to a broader segment of the community—including the private sector.

The SPoRT Paradigm: An Approach to Transitioning Research Capabilities to Weather Forecast Operations

The transition of NASA research and experimental data to the operational weather community for evaluation and use requires a committed partnership between data providers and end users. SPoRT bridges the gap between these two groups to make unique data and products developed by the research community available to the operational weather community. SPoRT derives a variety of products from a suite of EOS instruments and works with other data providers in the transition of other unique products to various end users. This paradigm is visually depicted in **Figure 1** (next page). Initial interaction with potential end users involves a site visit to the end-user facilities to learn about operational constraints and forecast issues. The knowledge gained from such a visit allows SPoRT staff members to match a particular research data or capability to a forecast problem. Potential approaches or solutions are typically discussed with end users to establish priorities and a baseline for collaboration.

[4] AWIPS stands for Advanced Weather Interactive Processing System, an advanced processing, display, and telecommunications system used by the NWS.

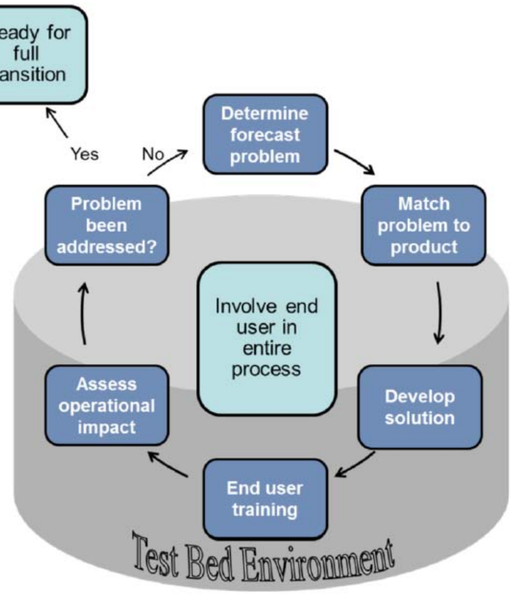


Figure 1. The SPoRT paradigm for successful transition of research data to the operational weather community.

This close interaction from the start reassures the end user that SPoRT is focused on helping them do their job. Potential solutions are demonstrated and refined in a *test bed environment* that simulates operational constraints. The test bed environment, which can be at SPoRT, an end-user facility, or even a third-party location, includes the use of end-user decision support systems (for the NWS these are typically AWIPS, NAWIPS[5], or AWIPS II) along with the pertinent real-time data streams. To make the transition successful, it is important that the new capabilities be integrated into the end-user decision-support system so that they can be easily used with other end-user data and capabilities. Solutions that seem viable (i.e., meet end user requirements for functionality, timeliness, display, etc.) are further demonstrated and ultimately evaluated in a broader collaborative arrangement that usually includes several collaborative offices or a quasi-operational test bed with similar interests or needs.

The successful use of transitioned products requires that end users be aware of the capabilities, strengths, and weaknesses of the solution being transitioned to their environment. SPoRT develops and conducts several different types of training, all of them conveying the application of the new data or technique, strengths, weaknesses, and limitations, and also includes end-user application examples, taken directly from the users' decision support systems.

The successful use of transitioned products requires that end users be aware of the capabilities, strengths, and weaknesses of the solution being transitioned to their environment. SPoRT develops and conducts several different types of training, all of them conveying the application of the new data or technique, strengths, weaknesses, and limitations—and also includes end-user application examples, taken directly from the users' decision support systems. This training takes the form of short self-guided modules, user-focused quick guides, distance training with the product developer, and even face-to-face science sharing sessions. Examples of these training modules can be found on the SPoRT website (*weather.msfc.nasa.gov/sport*) under *Transitions > Training*. End users often participate in developing these training aids.

It is important to understand the degree of impact the solution, new product, tool, or forecast capability may have in the operational environment. This assessment is usually done directly in the operational environment (with several end users) or at different locations. Short surveys are used to ascertain the impact of the new product on operational decision-making in the end-user environment. The surveys must not be a burden on the end user, but must allow for both quantitative and qualitative input on the utility of the product. The surveys used by SPoRT can be found on the SPoRT website under *Transitions > Surveys.* The activities of the transition process and the outcome of numerous end-user responses to the product surveys form an *assessment study*. These results are used to guide either broader product transition or a re-evaluation of the transition process.

[5] NAWIPS stands for the National Center for Environmental Prediction's Pre Advanced Weather Interactive Processing System. NAWIPS is being integrated into the second-generation AWIPS (AWIPS II) systems.

Partners and End Users

There are many individuals and groups who contribute to and benefit from the success of the SPoRT project. The primary *SPoRT stakeholders* (i.e., those who invest in and gain from the success of the project) are the NASA Research and Analysis and Applied Science Programs, the NOAA program offices, the NWS Office of Science and Technology (OST), and forecasters at the NWS Weather Forecast Offices (WFOs). Managers in these organizations provide funding and give guidance and direction to ongoing and future SPoRT research and transitional activities. The NWS and the collaborating WFOs are major stakeholders in the activity, since they provide direct in-kind support through their allocation of forecasters, Science and Operations Officers (SOOs), and Information Technology Officers (ITOs) in the transition of SPoRT products into AWIPS, and the education, training, and assessment assistance they provide. *SPoRT beneficiaries* are those who benefit from the success of the project. The NASA and NOAA entities are *direct beneficiaries* of the success of the SPoRT program. In addition to the WFOs—who interact with and receive products and capabilities from SPoRT—other beneficiaries include collaborating private sector partners who also receive value-added products to improve their weather forecasts. State and county emergency managers and the general public are *indirect beneficiaries* of SPoRT's success through improved forecasts provided by the WFOs.

*The primary **SPoRT stakeholders** (i.e., those who invest in and gain from the success of the project) are the NASA Research and Analysis and Applied Science Programs, the NOAA program offices, the NWS Office of Science and Technology (OST), and forecasters at the NWS Weather Forecast Offices (WFOs). Managers in these organizations provide funding and give guidance and direction to ongoing and future SPoRT research and transitional activities.*

Figure 2 shows the locations of SPoRT's *collaborative partners*—both supporting and end users. *Supporting partners* help SPoRT conduct the research and transitional activities by providing technical expertise, computational resources, data, and/or other enabling capabilities. *SPoRT end users* include forecasters at the various collaborating NWS WFOs, and other operational weather entities such as some of NOAA's National Centers for Environmental Prediction (NCEPs). The forecasters and environmental managers at these facilities have particular needs that can uniquely be met through the use of NASA's research capabilities. SPoRT currently works collaboratively with twenty-three WFOs and several NCEPs including the Weather Prediction Center, Ocean Prediction Center, and the National Hurricane Center. While the majority of the SPoRT end users are forecasters at these various WFOs and NCEPs across the U.S., the adaptation and use of SPoRT products in NOAA test beds, in proving ground activities, and for weather disaster applications show the relevance of SPoRT's activities to a broader segment of the applied weather community.

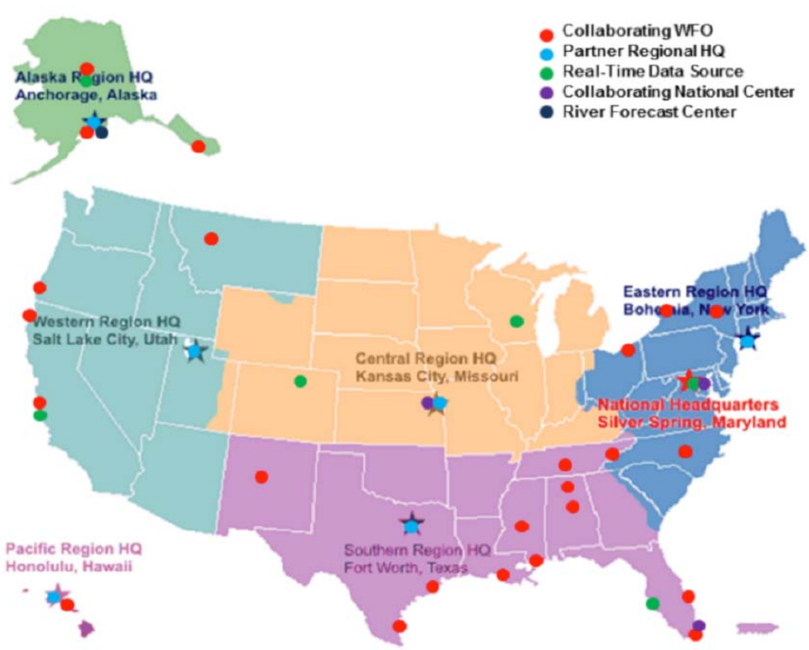


Figure 2. Map showing locations of SPoRT collaborative partners—including both supporting partners and end users.

SPoRT provides a suite of products from various NASA sensors that enhance the feature detection capabilities beyond that which is typically achieved using operational satellite data alone.

NASA Products and Research Capabilities Transitioned to End Users

SPoRT provides a suite of products from various NASA sensors to its end users for their decision-making processes. A list of these data and products and the forecast challenges that they support, are presented in **Table 1**. Basic MODIS imagery from NASA's Terra and Aqua satellites portrays atmospheric water vapor, cloud, and surface features—providing an increase in spatial resolution by a factor of sixteen over existing Geostationary Operational Environmental Satellite (GOES) imagery. Forecasters use the MODIS imagery to better understand the current environment (i.e., weather conditions), leading to improved situational awareness that helps support short-term forecasts and weather-related decisions. A suite of products derived from the basic imagery provides additional feature detection capability not readily available with operational satellite data. For example, the numerical difference in the shortwave and longwave infrared window channels on MODIS provides a useful means of discriminating between low clouds and fog, particularly at night when conventional visible imagery is unavailable. Derived products—such as sea surface temperature and various vegetation indices—provide qualitative information on variations in surface conditions affecting the development of clouds and other local weather processes.

The large data volume associated with the high-resolution MODIS imagery is often a challenge for operational decision support systems used by many end users. The data volume provided to end users is often reduced by using data fusion techniques. As an example, the production of red-green-blue (RGB) channel combinations provides

Table 1. SPoRT product suite provided to end users.

INSTRUMENT/PRODUCT	FORECAST PROBLEM
MODIS (onboard Terra and Aqua)	
Imagery (visible, 3.9, 6.7, 11 μm)	Improve situational awareness
Suite of RGB products (true and false color snow, air mass, night- and daytime microphysics, dust)	Cloud structure, obstructions to visibility, extent of snow cover
Fog/low cloud (3.9 - 11μm)	Improve situational awareness
Land and sea surface temperature (LST, SST)	Surface forcing for clouds and convection
SST and ice mask (Great Lakes and Arctic Ocean)	Coastal processes, lake effect precipitation
NDVI/GVF	Model initiation/improved forecasts
AMSR-E (onboard Aqua)/AMSR2 (onboard GCOM-W1)	
Rain rate, cloud water	Coastal weather, data in void regions
Sea surface temperature (SST)	Coastal weather
Total-Lightning Data (ground-based)	
Source/flash density	Severe weather, lightning safety
Multi-sensor composites	
SST (MODIS, GOES, AMSR)	Short-term weather forecast improvement
GOES-MODIS hybrid imagery (visible, 3.9, 6.7, 11μm)	Improved situational awareness
Hybrid RGB suite	Improved situational awareness
Suomi NPP Products	
VIIRS imagery (visible, 3.9, 11 μm)	Improved situational awareness
Suite of VIIRS RGB products (true, air mass (w/Crosstrack Infrared Scanner), night- and daytime microphysics, dust)	Cloud structure, obstructions to visibility, storm dynamics
VIIRS DNB (low light) – radiance, reflectance, RGB	Improved situational awareness

INSTRUMENT/PRODUCT	FORECAST PROBLEM
Passive Microwave	
Tropical Rainfall Measuring Mission (TRMM) Microwave Imager [TMI] 37 GHz (V/H), 85 GHz (V/H), composite	Precipitation monitoring, storm dynamics
Miscellaneous	
Land Information System (LIS) – soil moisture	Convective initiation, drought monitoring, flooding
Ozone Monitoring Instrument (OMI, onboard Aura)	
NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) sulfur dioxide (SO_2)	Volcanic ash monitoring
AIRS (onboard Aqua)	
Carbon monoxide (CO), ozone (O_3) imagery	Fires, air quality, storm dynamics

the information content of many channels in one product. SPoRT has developed and transitioned a suite of RGB composite imagery products to end users for: monitoring the change in surface visibility due to low clouds, fog, or smoke (true color); differentiating snow on the ground from low clouds (false color snow product); and identifying air mass properties and tropopause fold regions (air mass), cloud properties (day and night microphysics), and airborne dust (dust product). **Figure 3** presents an example of the RGB air mass product in AWIPS at a collaborative WFO. Note that by ingesting the data into the end-users' decision support systems, forecasters can integrate the data with other products and use existing tools to highlight characteristics of the research data for others to use.

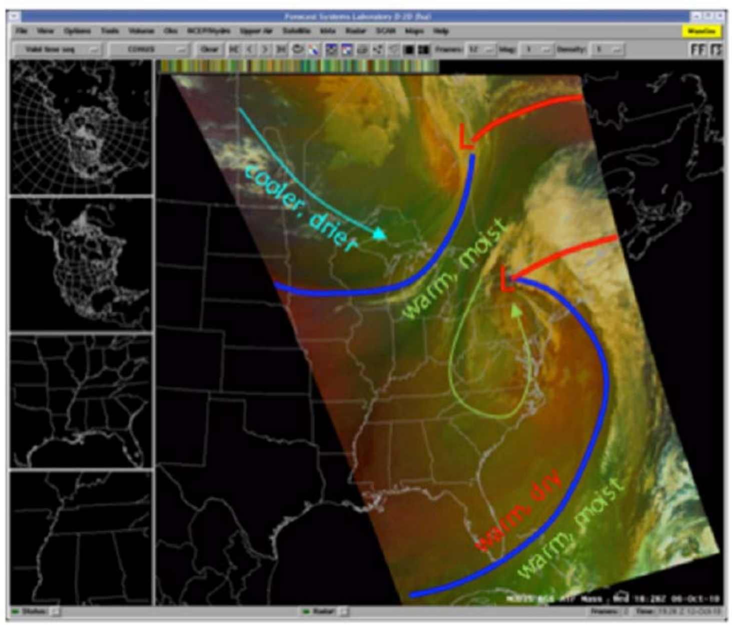


Figure 3. MODIS air mass product displayed in AWIPS.

Although the polar orbits of the Terra and Aqua satellites limit data availability to between two and four times daily at mid-latitudes, these image data and derived products are regularly used to improve situational awareness at most of the SPoRT collaborative weather offices. To address forecasters' complaints that it is difficult to animate the polar orbiting imagery because of the infrequent orbital passes and varying spatial coverage, SPoRT developed a geostationary–polar hybrid product from GOES and Polar-orbiting Environmental Satellites (POES), consisting of a continuous loop of operational GOES imagery complemented by MODIS imagery at the available overpass times. This hybrid image product preserves spatial resolution of the polar-orbiting data and the animation capability of the geostationary observing platform.

Several products from the AMSR-E instrument were made available to coastal forecast offices to monitor precipitation associated with approaching storms and tropical weather systems outside the range of land-based radar systems (until instrument failure in 2011). AMSR2 data from the Japanese Global Change Observation Mission–Water (GCOM-W1) satellite will soon be transitioned to replace the AMSR-E data stream.

Early in the collaborative process SPoRT also transitioned some unique total-lightning measurements from several NASA ground-based lightning networks. A number of WFOs have used lightning source and flash density products derived from total-lightning network data, along with Doppler radar, to improve the lead time for predicting severe-weather-producing tornadoes and damaging hail, as well as for lightning safety. An example of total-lightning data products from the North Alabama Lightning Mapping Array (NALMA), the Earth Networks Total Lightning Network[6], and the pseudo Geostationary Lightning Mapper (pGLM)—that previews future observing capabilities from the GOES-R satellite—as displayed in AWIPS II at the Huntsville WFO is presented in **Figure 4**. Transitioning these unique lightning products gives forecasters an edge in providing severe-weather guidance and lightning-safety information to the general public. The current distribution of total-lightning products includes data from seven different networks that have been transitioned to twelve WFOs and several NCEPs.

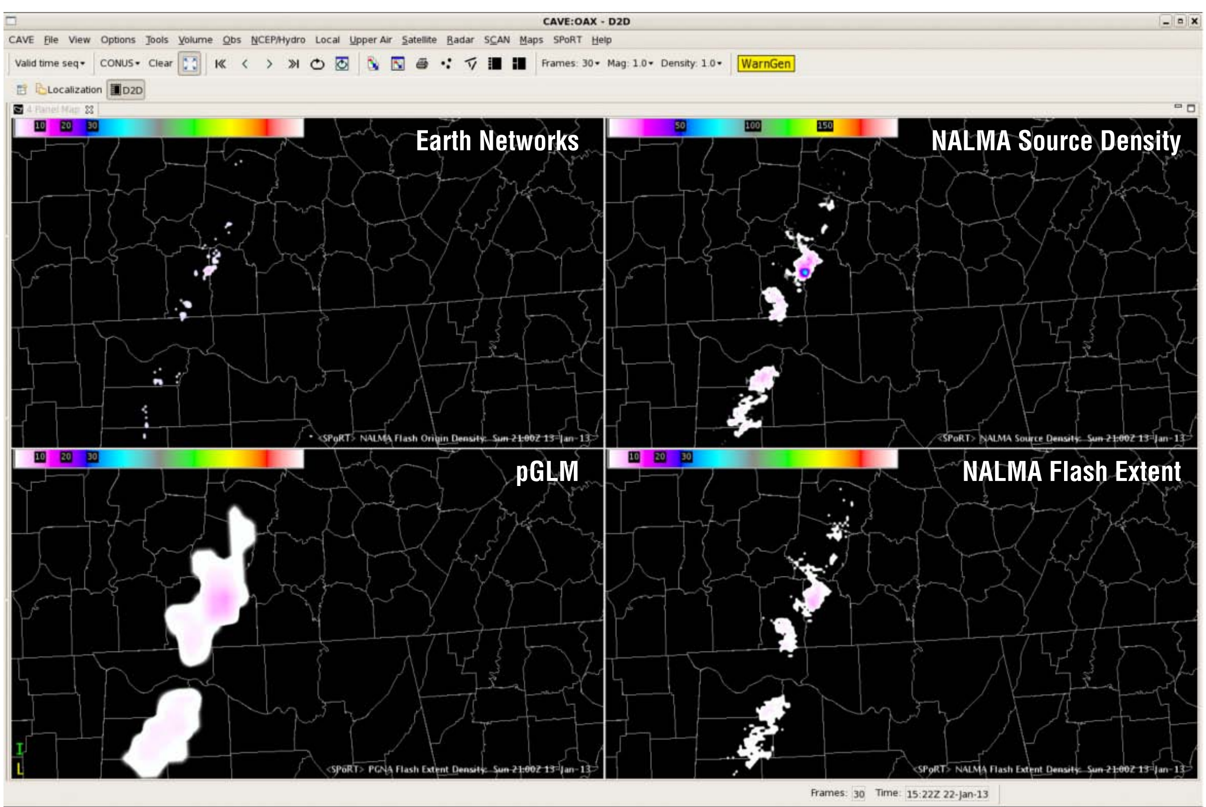
A number of WFOs have used lightning source and flash density products derived from total-lightning network data, along with Doppler radar, to improve the lead time for predicting severe-weather-producing tornadoes and damaging hail, as well as for lightning safety.

In addition to products derived directly from quasi-instantaneous swaths of data from a single sensor, SPoRT produces several multisatellite/multitime products such as the MODIS Normalized Difference Vegetation Index (NDVI) and Greenness Vegetation Fraction (GVF) products and the passive microwave/infrared cloud-free composite sea surface temperature product to improve local situational awareness and to assimilate into weather models run by individual WFOs for local model applications.

The success of SPoRT's transition to operations activities is measured in a number of ways including the number of peer-reviewed publications, transitional successes, community recognition, and end-user satisfaction. While the transition of a variety of new products and research capabilities to the end-user community is an important metric, the impact of the product and the satisfaction of the end user with the NASA research capabilities are equally important for both products transitioned and tools developed and provided to carry out successful transitions. Feedback on the success of these transitions is obtained through user surveys and documented in assessment studies and reports. Community recognition of SPoRT as an important partner to help facilitate other transitions is equally important. Recognition of SPoRT as "the place to go" for help in transitioning unique NASA weather products to the operational weather community demonstrates the success of the program.

[6] For more information, visit: *www.earthnetworks.com/OurNetworks/LightningNetwork.aspx*.

Figure 4. Total lightning products displayed in AWIPS II.



Opportunities for the community to partner with SPoRT are available through regular Research Opportunities in Space and Earth Science (ROSES) proposal solicitations. Newly developed transitional activities undertaken by other agencies—but using the SPoRT paradigm, capabilities, or information—are an additional measure of project success. Peer-reviewed publications on new research and transitional capabilities and techniques used to develop them are another key metric to document the success of the project. The publication rate may depend on the changing emphasis of the project; from time-to-time, more emphasis is put on transition rather than research. Publication of transitional results and assessments are also appropriate, although they may not always appear in peer-reviewed forums.

While transitioning EOS satellite data and products demonstrates the utility of the NASA data for weather forecasting and other societal applications, the research data also serve as precursor or proxy datasets to future NOAA operational instruments such as those of the Joint Polar Satellite System (JPSS) and the GOES-R satellite programs. Through the transition and use of data that simulate observing capabilities of instruments on these future observing systems (like the pGLM), SPoRT is helping prepare and train forecasters for the use of these next-generation capabilities. SPoRT has been participating in NOAA's JPSS and GOES-R Proving Ground activities for the last several years by working with its collaborative development partners (at the NOAA Cooperative Institute for Mesoscale Satellite Studies and the Cooperative Institute for Research in the Atmosphere) to transition these unique capabilities to operational end users. Eight of SPoRT's collaborative WFOs and all five of the collaborating NCEPs receive and evaluate the utility of proxy products in their forecast operations. Of particular interest is the use of data from the NASA/NOAA Visible Infrared Imaging Radiometer Suite (VIIRS) on the Suomi National Polar-orbiting Partnership (NPP) satellite, not only to simulate the spatial and spectral capabilities of the future GOES-R Advanced Baseline Imager (ABI), but also to directly improve situational awareness and short-term weather forecast capabilities for a variety of end users. SPoRT provides high-resolution imagery from VIIRS [including a suite of RGB products, and radiance and reflectance products from the new low-light sensor [or day-night band (DNB)] to its end users. The DNB senses reflected moonlight from clouds, smoke, and surface features and visible emission from fires and city lights, and improves the nighttime detection of atmospheric features when only coarse-resolution infrared data are available.

While transitioning EOS satellite data and products demonstrates the utility of the NASA data for weather forecasting and other societal applications, the research data also serve as precursor or proxy datasets to future NOAA operational instruments such as those of the Joint Polar Satellite System (JPSS) and the GOES-R satellite programs.

Summary and Future Opportunities

Through these efforts, SPoRT strives to be a focal point and facilitator for the transfer of unique Earth science technologies to the operational weather community, with an emphasis on short-term forecasting. To achieve this vision, the SPoRT project will continue to address new data and technologies and develop and test solutions to critical forecast problems, and integrate solutions into end-user decision-support tools.

Future SPoRT activities will focus both on diagnostic analysis of new NASA Decadal Survey data, such as those from the upcoming Soil Moisture Active Passive (SMAP) mission, as well as data from the Global Precipitation Measurement (GPM) missions and the assimilation of these data into regional weather forecast models using land data assimilation capabilities within the NASA Land Information System. SPoRT plans to transition additional total-lightning network data and to generate additional value-added lightning products for use by the operational weather community. New RGB products and accompanying training are also planned for the near future. Given its commitment to be at the forefront, SPoRT will transition all current and future products into the new NWS decision-support system (AWIPS II) as it is implemented across the country. ■

NASA Intensifies Hurricane Studies with CYGNSS

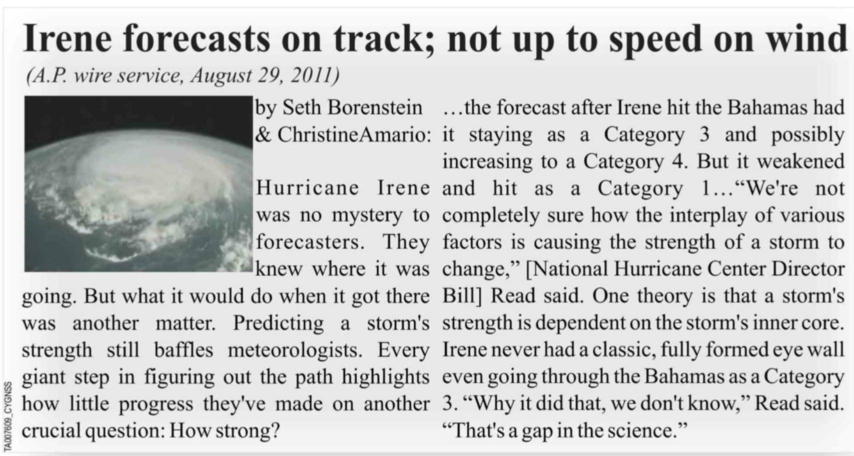
Christopher Ruf, University of Michigan, Space Physics Research Laboratory, cruf@umich.edu
Allison Lyons, University of Michigan, adlyons@umich.edu
Alan Ward, NASA's Goddard Space Flight Center/Wyle, alan.b.ward@nasa.gov

Historically, it has been difficult to obtain space-based measurements of ocean surface vector winds in regions with heavy precipitation.

Rationale for CYGNSS

Hurricane track forecasts have improved in accuracy by about 50% since 1990, largely as a result of improved mesoscale and synoptic modeling and data assimilation. On the other hand, in that same period there has been essentially no improvement in the accuracy of intensity forecasts—an observation that is widely recognized not only by national research institutions[1], but also by the popular press—see **Figure 1**.

A hurricane intensity forecast is critically dependent on accurate wind measurements in the core of the developing tropical cyclone. Current hurricane intensity forecasts are limited by two factors: inaccuracy of current ocean surface wind measurements and inadequate sampling of the rapidly evolving core environment. Historically, it has been difficult to obtain space-based measurements of ocean surface vector winds[2] in regions with heavy precipitation. While supplementing satellite observations with aircraft-based observations has helped improve accuracy in some instances, wind-speed estimates in the inner core of a hurricane continue to be a challenge.


Irene forecasts on track; not up to speed on wind

(A.P. wire service, August 29, 2011)

by Seth Borenstein & ChristineAmario: Hurricane Irene was no mystery to forecasters. They knew where it was going. But what it would do when it got there was another matter. Predicting a storm's strength still baffles meteorologists. Every giant step in figuring out the path highlights how little progress they've made on another crucial question: How strong?

…the forecast after Irene hit the Bahamas had it staying as a Category 3 and possibly increasing to a Category 4. But it weakened and hit as a Category 1…"We're not completely sure how the interplay of various factors is causing the strength of a storm to change," [National Hurricane Center Director Bill] Read said. One theory is that a storm's strength is dependent on the storm's inner core. Irene never had a classic, fully formed eye wall even going through the Bahamas as a Category 3. "Why it did that, we don't know," Read said. "That's a gap in the science."

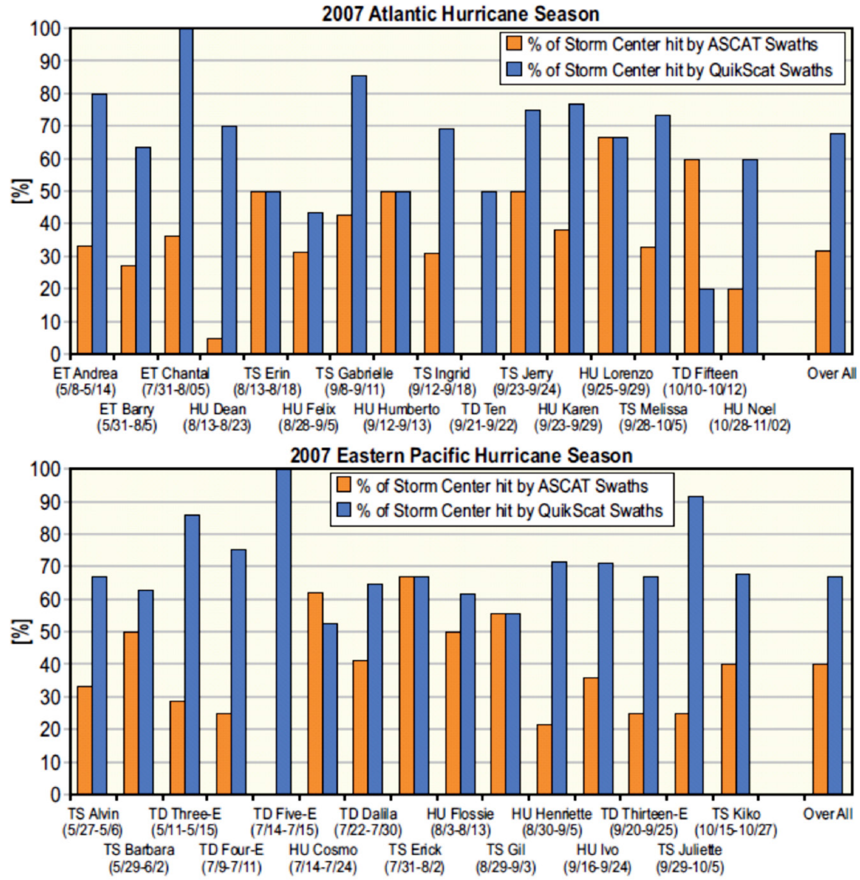
TA007609_CYGNSS

Figure 1: Excerpt from article on the Associated Press Wire Service, August 29, 2011.

Tropical cyclones form from *mesoscale convective systems* (MCSs[3]). In the tropics, MCSs account for more than half of the total rainfall, and their development is critically dependent on complex interactions between ocean surface properties, moist-atmosphere thermodynamics, radiation, and convective dynamics. Unfortunately, most current space-based active and passive microwave instruments are in polar low-Earth orbits (LEOs) that maximize global coverage but leave significant "data gaps" over the tropics. Further, a single, broad-swath, high-resolution scatterometer system cannot resolve synoptic-scale spatial detail everywhere on the globe, and in particular not over the tropics. The revisit times of current on-orbit instruments range between 12 hours and several days, and are similarly not sufficient to capture the rapidly changing environment at the core of a tropical cyclone.

As a striking example, **Figure 2** (next page) shows the percentage of times that the core of every tropical depression, storm, and cyclone from the 2007 Atlantic and Pacific storm seasons was successfully imaged by the Quick Scatterometer (QuikSCAT) or Advanced Scatterometer (ASCAT). Sometimes, the core is missed when an organized system passes through an imager's coverage gap; other times, it is because the storm's motion is appropriately offset from the motion of the imager's swath. The figure highlights the fact that, in many cases, tropical cyclones are observed

[1] *Hurricane Warning: The Critical Need for a National Hurricane Research Initiative*, National Science Foundation, NSB-06-115, 2007; Hurricane Forecast Improvement Project, NOAA, 2008
[2] These include NASA's Quick Scatterometer (QuikSCAT), which flew on the SeaWinds mission, the Advanced Scatterometer (ASCAT) on the European Organization for the Exploitation of Meteorological Satellites' (EUMETSAT) METOP series of satellites, and the Oceansat-2.
[3] Tropical cyclones, mesoscale convective complexes, squall lines, lake effect snow, and polar lows are all weather phenomena that form from MCSs.



ET = Extratropical **HU** = Hurricane **TD** = Tropical Depression **TS** = Tropical Storm

Figure 2. These graphs show the percentage of times the center of named tropical cyclones were observed by either the QuikSCAT (blue) or ASCAT (orange) polar-orbiting scatterometers during the 2007 Atlantic [*top graph*] and Pacific [*bottom graph*] hurricane season. Poor performance results from the coverage gaps and infrequent revisit times are characteristic of polar-orbiting wide-swath imagers.

less than half the time. One particularly egregious case is Hurricane Dean, for which ASCAT was able to observe it during less than 5% of its life cycle.

The goal of NASA's Cyclone Global Navigation Satellite System (CYGNSS) is to resolve these two principal deficiencies with current tropical cyclone intensity forecasts. Selected as a Venture Class mission[4], CYGNSS–with a tentative launch date of 2016–uses an innovative design that employs eight small satellites carried into orbit on a single launch vehicle. The eight satellites will comprise a *constellation* that will allow the observatories to fly in close proximity to each other to measure the ocean surface wind field with unprecedented temporal resolution and spatial coverage, under all precipitating conditions, and over the full dynamic range of wind speeds experienced in a tropical cyclone. (The constellation concept is described in greater detail below.) It will do so by combining the all-weather performance of Global Positioning System (GPS)-based *bistatic scatterometry* with the sampling properties of a dense microsatellite (microsat) constellation—see *CYGNSS Heritage: Using GPS Reflectometry for Geophysical Measurements* on page 17. In orbit, the observatories will receive both direct and reflected signals from GPS satellites. The direct signals pinpoint CYGNSS observatory positions, while the reflected signals respond to ocean surface roughness, from which wind speed is retrieved. **Figure 3** illustrates the improvements that

The system will allow us to probe the inner core of hurricanes for the first time from space to better understand their rapid intensification.

*—**Christopher Ruf** [University of Michigan—CYGNSS Principal Investigator]*

[4] *Venture Class* missions are intended to be principal-investigator-led, rapidly developed, cost-constrained missions/instruments for NASA's Earth Science Division. The September–October 2010 issue of *The Earth Observer* [**Volume 22**, **Issue 5**, pp. 13-18] described the program. CYGNSS was selected in June 2012 from among several proposals submitted for the EV-2 Announcement of Opportunity.

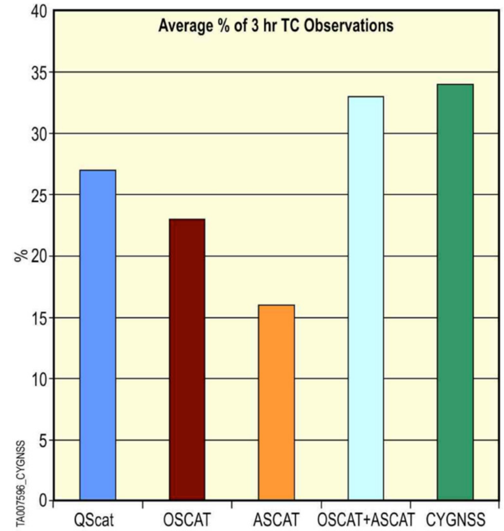


Figure 3. This graph shows the percentage of three-hour intervals during the 2005 Atlantic hurricane season in which each of three ocean wind scatterometers [QuikSCAT (QScat), OSCAT, and ASCAT] would have sampled the inner core region of every tropical cyclone that occurred that year. Also included is the percentage sampled by the combined OSCAT+ASCAT constellation (since these two scatterometers are currently operational) and the percentage that would have been sampled by CYGNSS, had it been in orbit at the time. CYGNSS will have a substantially higher sampling capability of tropical storm inner core regions than any one scatterometer—and will be comparable to the combined capabilities of ASCAT and OSCAT.

CYGNSS observations are expected to achieve over those from current scatterometers, using the 2005 Atlantic hurricane season as an example.

CYGNSS Measurement Concept: Constellation Flying Provides More Coverage

CYGNSS relies on an innovative design that will deploy eight observatories flying together in a constellation—an approach that has a heritage in Earth science observations. For example, the A-Train[5] constellation consists of several satellite missions flying within precise distances of one another. NASA and its partners have also deployed multiple satellites from a single launch vehicle. The Gravity Recovery and Climate Experiment (GRACE[6]) satellites, for example, were launched by the same vehicle and fly in precision formation—a key feature of the mission concept. Similarly, the CloudSat and the Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite missions were comanifested. However, as one might expect, launching eight satellites from a single launch vehicle presents new engineering challenges that must be carefully planned and executed.

CYGNSS relies on an innovative design that will deploy eight observatories flying together in a constellation—an approach that has a heritage in Earth science observations.

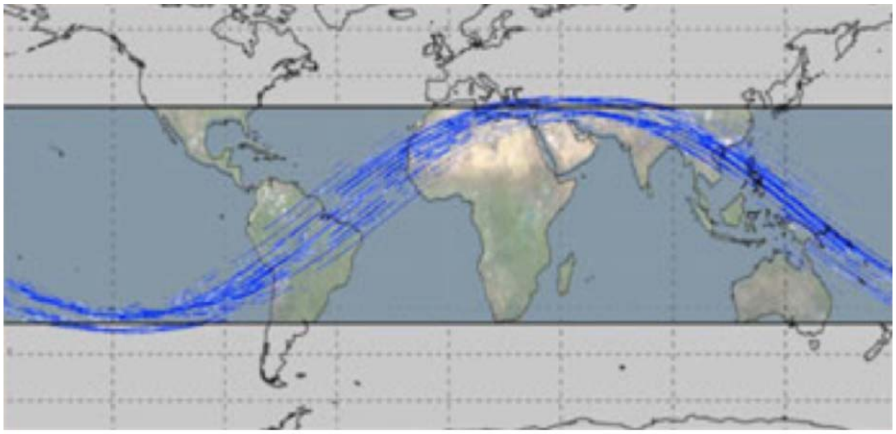
As described earlier, sampling by a single observatory results in both poor spatial coverage and temporal resolution of tropical cyclone evolution. The constellation approach overcomes these limitations—see *Coverage Comparison: CYGNSS Constellation versus ASCAT* on the next page. The constellation will sample the ocean more frequently than a single satellite would, resulting in a more highly resolved view of the ocean's surface. Each observatory simultaneously tracks scattered signals from up to four independent transmitters in the operational GPS network. The number of observatories and orbital inclination are chosen to optimize the tropical cyclone sampling properties. The result is a dense cross-hatch of sample points on the ground that cover the critical latitude band between ±35° with an average revisit time of 4.0 hours. The spatial coverage possible with CYGNSS is illustrated in **Figure 4** on the next page.

The CYGNSS Observatories: Eight Self-contained Digital Doppler Mappers

The CYGNSS observatory design accommodates the solar power arrays, the GNSS antennas required by the Delay Doppler Mapping Imager (DDMI), and other launch

[5] "A-Train" is the popular nickname for the Afternoon Constellation of satellites that includes NASA's Aqua, Aura, CloudSat, and the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) missions, as well as the Japan Aerospace Exploration Agency's (JAXA) Global Change Observation Mission-Water (GCOM-W1). The second Orbiting Carbon Observatory (OCO-2) is expected to join them in 2014. For more information, visit: *atrain.nasa.gov*.

[6] A description of the GRACE mission and its accomplishments during its first ten years in orbit appears in the March–April 2012 issue of *The Earth Observer* [**Volume 24**, **Issue 2**, pp. 4-13].



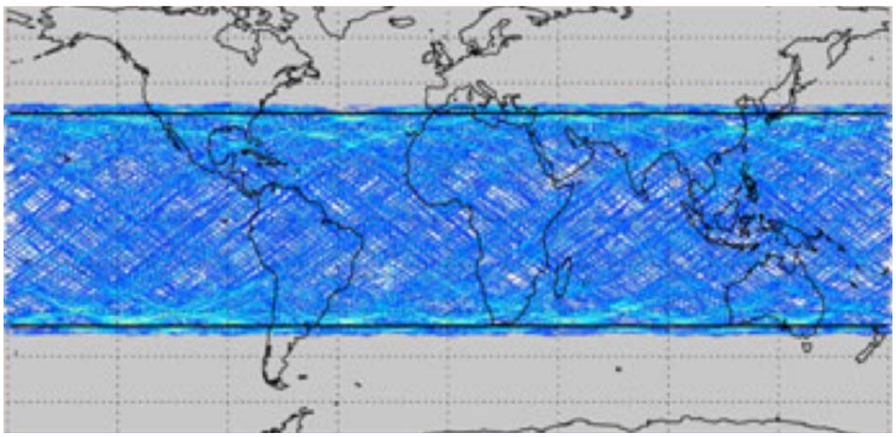
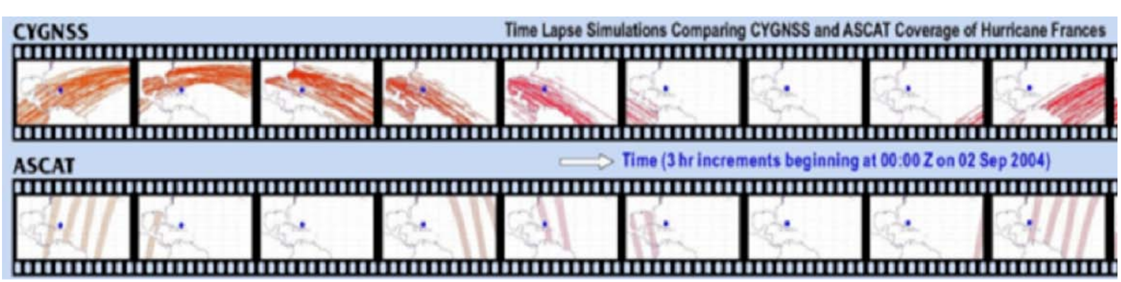


Figure 4: Each low-Earth-orbiting CYGNSS observatory will orbit at an inclination of 35° and be capable of measuring 4 simultaneous reflections, resulting in 32 wind measurements per second across the globe. The orbit inclination was selected to maximize the dwell time over latitudes at which hurricanes are most likely to occur. The result will be high-temporal-resolution wind-field imagery of tropical cyclone genesis, intensification, and decay. Shown here are planned CYGNSS ground tracks for 90 minutes [*top*] and a full 24-hour period [*bottom*].

constraints—see **Figure 5** on the next page. The design also incorporates functional and selective redundancy for critical systems. Observatory attitude is three-axis stabilized using horizon sensors, a magnetometer, pitch momentum wheels, and torque rods. Observatory mass and power are estimated to be ~18 kg (~40 lbs) and ~49 W, respectively.

Coverage Comparison: CYGNSS Constellation versus ASCAT

This figure depicts a time-lapse simulation comparing the spatial and temporal sampling properties of CYGNSS [*top row*] and ASCAT [*bottom row*], assuming they had both been in orbit on September 2, 2004, when Hurricane Frances made U.S. landfall. Data from satellite coverage models for both ASCAT and CYGNSS were projected onto archival storm track records for Frances to create the maps. Each frame represents all samples taken within a three-hour interval. The inner core of Frances is shown as a large blue dot in each frame. ASCAT, with its relatively narrow swath width, does not sample the inner core very frequently, whereas the much wider and more dispersed effective swath of the CYGNSS constellation would have allowed for much more-frequent sampling. The average revisit time for inner-core sampling for CYGNSS is predicted to be 4.0 hours, with a median revisit time of 1.5 hours.



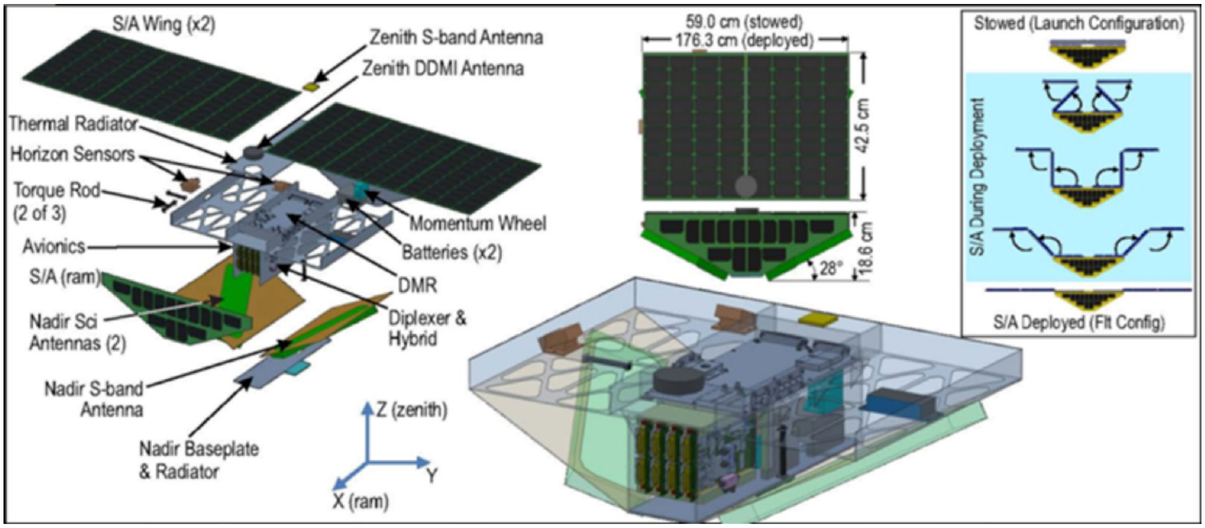


Figure 5. This figure shows a CYGNSS observatory. The exploded view shows individual subsystems, including the science payload's Delay Doppler Mapping Imager (DDMI) antennas and receiver electronics [DMR]. Solar array deployment, performed after ejection from the launch deployment module, is also illustrated.

Each observatory is deployed from the launch vehicle with solar arrays stowed, and can remain in this configuration indefinitely. After deployment from the launch vehicle, each observatory transitions automatically through three initial states before reaching *Standby Mode,* where it will remain until all eight satellites are ready for use. Upon completion of commissioning activities, the observatories will transition into the *Science Mode* of operation. At this point, aside from the brief engineering verification test modes described below, the DDMI is set to Science Mode for the duration of the mission[7]. In Science Mode, subsampled Delay Doppler Maps (DDMs) are generated onboard and downlinked with a 100% duty cycle.

In developing the design concepts for the CYGNSS observatories, the systems engineering team sought to ensure the safety of the observatories without ground intervention. The onboard systems have been designed to minimize the need for ground-based, time-tagged command sequences for each observatory for routine operations. This helps to enable a simplified and automated sequence of science observations and engineering calibration procedures that can operate unattended during normal Science Mode. With the DDMI in its Science Mode, the observatory is set to maintain all nominal operations without additional commands. The primary "routine" activity performed on a regular basis is communication with the ground network to downlink the accumulated science and engineering data.

The onboard systems have been designed to minimize the need for ground-based, time-tagged command sequences for each observatory for routine operations. This helps to enable a simplified and automated sequence of science observations and engineering calibration procedures that can operate unattended during normal Science Mode.

Launch/Commissioning Activities

CYGNSS is currently scheduled for launch in 2016; details (e.g., location and launch vehicle) are still to be determined. After launch, the mission begins with *engineering commissioning* of the observatories and science instruments. Additional *science commissioning* activities for the observatories will begin once the solar arrays are deployed on every observatory in the constellation and will continue for a period of two-to-four weeks.

Engineering Commissioning

Since each observatory functions independently, *engineering commissioning* activities for satellites and instruments may progress in an interleaved manner: Within a single communications pass, activities will be performed on a single observatory; however, it is not necessary to complete all commissioning tasks on one observatory before progressing to the next observatory in the constellation. Similarly, it is also unnecessary to ensure that each observatory is at the same "step" in a commissioning sequence. This independence allows a flexible scheduling approach to be used in setting up commissioning passes and does not delay commissioning activities for all observatories if a single satellite requires extra time while an off-nominal issue is being addressed.

[7] The only other interruption to Science Mode will be brief returns to *Calibration/Validation Mode* performed biannually—see **Data Products** section for details.

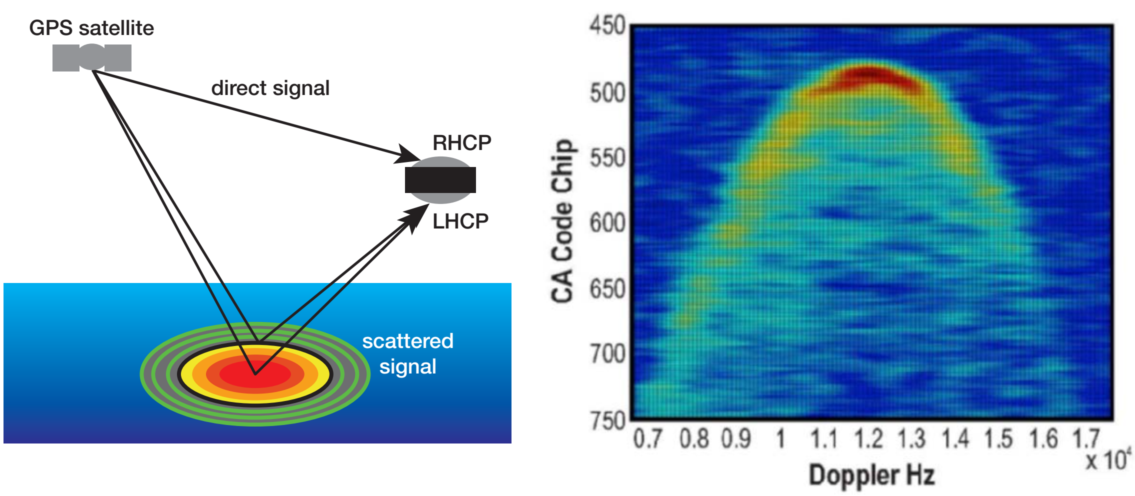
CYGNSS Heritage: Using GPS Reflectometry for Geophysical Measurements

For some years, GPS receivers have been used to provide position, velocity, and time measurements to satellite platforms in low Earth orbit. In a similar way, they are also used for ground-based navigation. Beyond navigation however, GPS signals have been increasingly used for remote sensing. Signals at *L-band*[1] —with a bandwidth between 2 and 20 MHz—are broadcast globally from an altitude of ~20,000 km (~12,427 mi) and are used to measure, amongst other things, tectonic plate motion and ionospheric and tropospheric parameters. Furthermore, signals from other Global Navigation Satellite Systems (GNSS[2]) are becoming available: There will soon be more than 120 such signal sources in space.

The United Kingdom Disaster Monitoring Constellation (UK-DMC-1[3]) space-based demonstration mission showed that a microsatellite-compatible passive instrument potentially could make valuable geophysical measurements using *GPS reflectometry.* The left side of the figure below diagrams how the process works. The direct GPS signal is transmitted from the orbiting GPS satellite and received by a right-hand circular polarization (RHCP) receive antenna on the *zenith* (i.e., top) side of the spacecraft that provides a coherent reference for the coded GPS transmit signal. The quasispecular, forward-scattered signal that returns from the ocean surface is received by a *nadir-* (i.e., downward-) looking left-hand circular polarization (LHCP) antenna on the nadir side of the spacecraft. The scattered signal contains detailed information about its roughness statistics, from which local wind speed can be derived.

The image on the right below shows *scattering cross section* as measured by UK-DMC-1 and demonstrates its ability to resolve the spatial distribution of ocean surface roughness. This type of scattering image is referred to as a *Delay Dopplar Map* (DDM).

There are two different ways to estimate ocean surface roughness and near-surface wind speed from a DDM. The *maximum scattering cross-section* (the darkest shades in the graph) can be related to roughness and wind speed.



[*Left.*] GPS signal propagation and scattering geometries for *ocean surface bistatic quasispecular scatterometry*. The position of the spacecraft is determined from the direct GPS signal; the surface winds are determined by the indirect signal (scattered off the ocean surface). Combining the position and scattering information allows for the creation of Delay Doppler Maps (DDM), from which ocean surface vector wind speeds can be inferred. [*Right.*] An example DDM showing the spatial distribution of the ocean surface scattering measured by the UK-DMC-1. Scattering cross section is plotted as a function of Doppler Shift (x-axis) and propagation time of flight (y-axis), which is measured in units of Coarse Acquisition GPS Code or "Chips." See text for further details.

[1] The L-band portion of the electromagnetic spectrum covers the range from 1 to 2 GHz, and is commonly used for satellite communications.
[2] The current Global Navigation Satellite System (GNSS) currently includes two fully operational networks: the U.S. Global Positing Satellite (GPS) system and the Russian Globalnaya Navigatsionnaya Sputnikovaya Sistema (GLONASS). By 2020 the European Union [Galileo] and China [COMPASS] should have fully functional GNSS systems. Other nations are also working on their own systems, that may eventually become part of the network.
[3] The Disaster Monitoring Constellation (DMC) was deployed in 2003. It was constructed by a U.K.-based company called Surrey Satellite Technology Ltd. (SSTL) and the University of Surrey (Guildford, U.K.), and is comprised of several remote sensing satellites operated for the Algerian, Nigerian, British, and Chinese governments by DMC International Imaging.

This, however, requires *absolute calibration* of the DDM, which is not always available. Wind speed can also be estimated from a *relatively calibrated* DDM, using the *shape of the scattering arc* (the lighter shades in the graph). The arc represents the departure of the actual *bistatic scattering* from the theoretical *purely specular case*—i.e., scattering from a perfectly flat ocean surface—which appears in the DDM as a single-point scatterer. The latter approach imposes more-relaxed requirements on instrument calibration and stability than does the former. However, it derives its wind speed estimate from a wider region of the ocean surface, and thus has lower spatial resolution.

After UK-DMC-1, development of wind-speed retrieval algorithms from DDMs became an active area of research and resulted in the design of a new instrument called the Space GNSS Receiver – Remote Sensing Instrument (SGR-ReSI[4]). Like its predecessor, the instrument can make valuable scattering measurements using GPS, but it has greater onboard data storage capacity and can process the raw data into DDMs in real time. It also has been designed with flexibility so it can be programmed while in orbit for different purposes—e.g., tracking new GNSS signals when needed, or applying spectral analysis to received signals.

In effect, the SGR-ReSI fulfils in one module what has historically been handled by three separate units on earlier spacecraft. Specifically,

- it performs all the core functions of a space GNSS receiver, with front-ends supporting up to eight single or four dual-frequency antenna ports;
- it is able to store a quantity of raw sampled data from multiple front ends, or processed data in its one-gigabyte solid-state data recorder; and
- it has a dedicated reprogrammable field-programmable gate array (FPGA) coprocessor (a Xilinx *Virtex 4*).

Each CYGNSS observatory will be equipped with a Digital Doppler Mapping Instrument (DDMI), based on the SGR-ReSI design. The DDMI will generate DDMs continuously at a low data rate, which will provide a source for ocean roughness measurements across the ocean. In special situations, such as when passing over an active tropical cyclone, the instrument can be operated in *Raw Data Mode*, where 60 seconds of raw sampled data is accumulated. This allows researchers to fully analyze and re-analyze the acquired data using different processing schemes to ensure that the nominal DDM mode of operation is not losing important geophysical data.

[4] SSTL and the University of Surrey teamed with the National Oceanographic Centre in Southampton, U.K., University of Bath, and Polar Imaging Ltd. to develop SGR-ReSI.

Science Commissioning

Science commissioning takes place after engineering commissioning activities are completed. At this time, the observatory will be operated in its nominal Science Mode, and preliminary Level-2 (L2) wind speed data products[8] will be produced. A large wind field intercomparison database will be assembled from a variety of sources including buoys, other satellite-based instruments, and global meteorological and oceanographic model assimilations. During science commissioning the ground-processing algorithms used to produce L2 data will be refined. The data assimilation tools, which ingest L2 data into numerical weather prediction forecast models, are also tested.

A large wind field intercomparison database will be assembled from a variety of sources including buoys, other satellite-based instruments, and global meteorological and oceanographic model assimilations.

Ground System Overview

The CYGNSS ground system—shown in **Figure 6**, next page—consists of: a Mission Operations Center (MOC), located at the Southwest Research Institute's (SwRI) Planetary Science Directorate in Boulder, CO; a Science Operations Center (SOC), located at the University of Michigan's Space Physics Research Laboratory in Ann Arbor, MI; and a Ground Data Network, operated by Universal Space Network (USN) and

[8] A list of planned CYGNSS data products appears at *aoss-research.engin.umich.edu/missions/cygnss/data-products.php*. Data are expected to be publicly available about a year after launch.

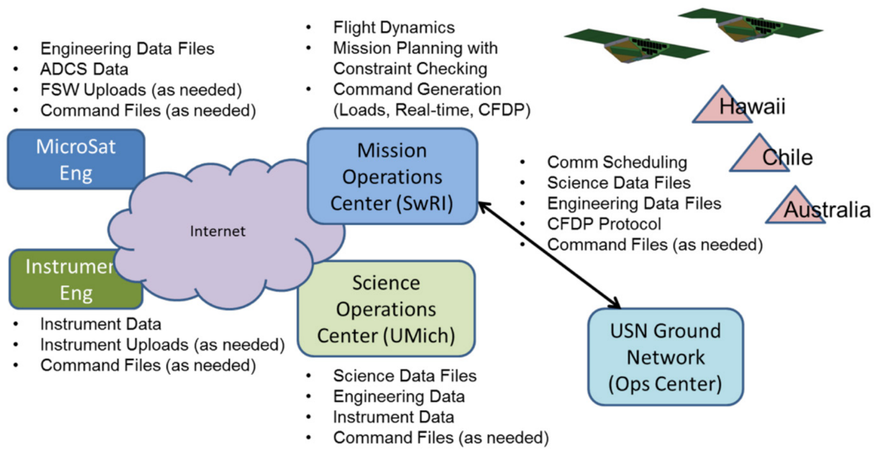


Figure 6. Diagram showing an overview of the components of the CYGNSS ground system.

consisting of existing *Prioranet*[9] ground stations in South Point, HI, in Santiago, Chile, and in Western Australia, some 400 km (~248.5 mi) south of Perth, and at the MOC facility. Additional interfaces between the MOC and the microsat engineering team and the DDMI instrument engineering teams are also supported. The MOC coordinates operational requests from all facilities and develops long-term operations plans. Each of these components is described in more detail below.

Mission Operations Center (MOC)

During the mission the CYGNSS MOC is responsible for mission planning, flight dynamics, and command and control tasks for each of the observatories in the constellation. These primary MOC tasks include:

- Coordinating activity requests;
- scheduling ground network passes;
- maintaining the Consultative Committee for Space Data Systems (CCSDS) File Delivery Protocol (CFDP) ground processing engine;
- collecting and distributing engineering and science data;
- tracking and adjusting the orbit location of each observatory in the constellation;
- trending microsat data;
- creating real-time command procedures or command loads required to perform maintenance and calibration activities; and
- maintaining configuration of onboard and ground parameters for each observatory.

Science Operations Center (SOC)

The CYGNSS SOC will be responsible for the following items related to calibration/validation activities, routine science data acquisition and special requests, and data processing and storage:

- Supporting DDMI testing and validation both prelaunch and on-orbit;
- providing science operations planning tools;
- generating instrument command requests for the MOC;
- processing Levels 0 through 3 science data; and

The CYGNSS ground system consists of: a Mission Operations Center (MOC), located at the Southwest Research Institute's (SwRI) Planetary Science Directorate in Boulder, CO; a Science Operations Center (SOC), located at the University of Michigan's Space Physics Research Laboratory in Ann Arbor, MI; and a Ground Data Network, operated by Universal Space Network (USN) and consisting of existing Prioranet ground stations in South Point, HI, in Santiago, Chile, in Western Australia, some 400 km (~248.5 mi) south of Perth, and at the MOC facility.

[9] *Prioranet* was specifically designed for comprehensive communications and ground support to Earth-orbiting satellite. For more information, visit: *www.sscspace.com/ground-network-prioranet-1*.

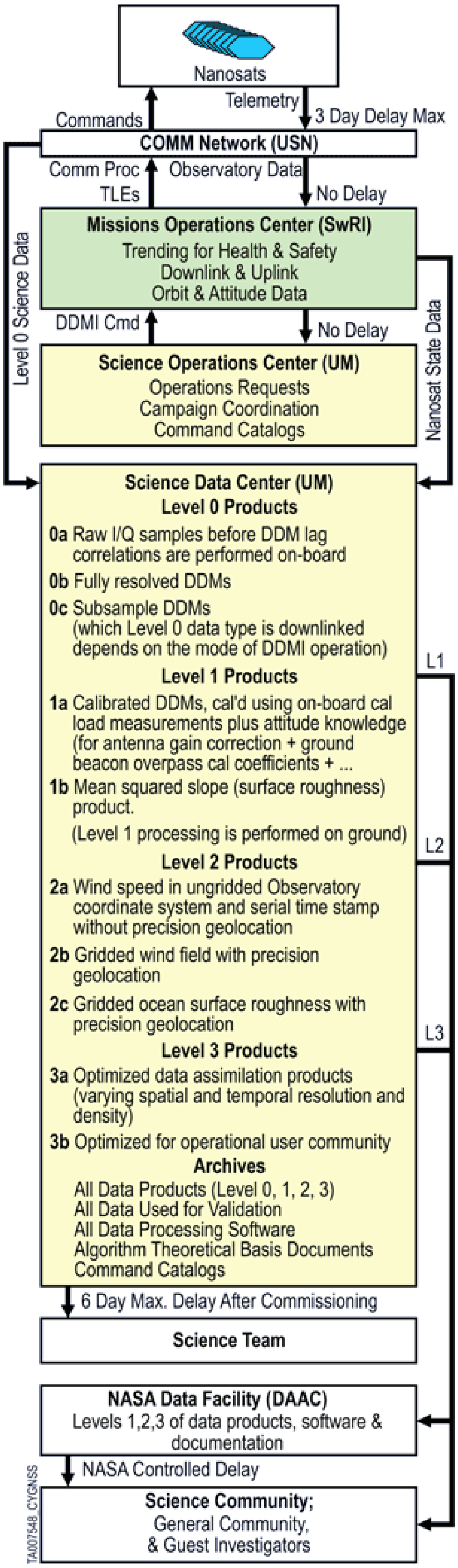


Figure 7. *CYGNSS Data Flowchart.* This figure illustrates how the data flows from the CYGNSS observatories to the various elements of the ground system for processing, to the DAAC for archiving, to the science team for analysis, and ultimately to the broader user community for application. The planned CYGNSS data products are also listed.

- archiving Level 0-3 data products, DDMI commands, code, algorithms, and ancillary data at a NASA Distributed Active Archive Center.

Ground Data Network

CYGNSS selected USN to handle ground communications because of their extensive previous experience with missions similar to CYGNSS. Collocation of a back-up CYGNSS MOC server at the USN Network Management Center (NMC) can also be supported.

Each of the observatories in the CYGNSS constellation will be visible to the three ground stations within the USN for periods that average between 470 and 500 seconds of visibility per pass. Each observatory will pass over each of the three ground stations six-to-seven times each day, thus providing a large pool of scheduling opportunities for communications passes. MOC personnel will schedule passes as necessary to support commissioning and operational activities. High-priority passes will be scheduled to support the solar array deployment for each observatory.

For all subsequent stages, the MOC schedules nominal passes for the USN stations for each observatory in the constellation per the USN scheduling process. Each observatory can accommodate gaps in contacts with storage capacity for greater than 10 days' worth of data with no interruption of science activities.

Data Products

The data returned from CYGNSS are expected to expand our knowledge of the rapidly changing environment in the core of a developing tropical cyclone—see **Figure 7** for details on data flow and a list of planned CYGNSS data products. The SOC is responsible for data product development and dissemination. After science commissioning is complete and the mission enters its nominal science operations stage, the L2 data will be made available for public release. The CYGNSS science team members will use the fully calibrated L2 data for their own research and make it available to the external user science community and eventually to operational users. Calibration/validation assessment of L2 data quality continues for the life of the mission using an updated version of the same wind field intercomparison database used during science commissioning. Twice a year, nominally at the beginning and end of the Atlantic hurricane season, engineering performance will be verified by a brief (approximately two-week) repeat of the instrument calibration activities performed during engineering commissioning.

Application of CYGNSS to Hurricane Forecasting

As stated above, the primary goals of CYGNSS are to measure ocean surface wind speeds in all weather conditions—including those inside the eyewall—and measuring wind speed with sufficient frequency to resolve genesis and rapid intensification in the inner core of a tropical cyclone. In addition to success with these two primary objectives, there is likely to be a secondary benefit with direct societal relevance: The CYGNSS team will produce and provide ocean surface wind speed data products to the operational hurricane forecast community and help them assess the value of these products for use in their retrospective studies of potential new data sources. In time, this information will be incorporated into models used to predict the evolution of hurricanes.

While improved hurricane forecasting is not the CYGNSS mission's primary objective, it is hoped that hurricane prediction—in particular, hurricane intensity forecasts—will improve as a result of the data that the CYGNSS mission returns.

*While improved hurricane forecasting is **not** the CYGNSS mission's primary objective, it is hoped that hurricane prediction—in particular, hurricane intensity forecasts—will improve as a result of the data that the CYGNSS mission returns.*

Acknowledgment

Parts of this article have been extracted from some proceedings papers of a recent technical conference focusing on CYGNSS. The citations for those papers can be found at *aoss-research.engin.umich.edu/missions/cygnss/reference-material.php*.

For More Information

Some of the text and graphics that appear in this article have been extracted from these sources and adapted for use in *The Earth Observer*:

General information about the CYGNSS mission (e.g., science, technology, data products)
CYGNSS-Michigan.org.

List of references on topics mentioned herein (e.g., GNSS, ocean surface scattering, aircraft observations, spaceborne observations)
aoss-research.engin.umich.edu/missions/cygnss/reference-material.php. ■

Aqua AIRS Version 6 Level 3 Data Release

The Atmospheric Infrared Sounder (AIRS) Project and NASA's Goddard Earth Sciences Data and Information Services Center (GES DISC) are pleased to announce the availability of *Aqua AIRS Version 6 Level 3* data. The AIRS Version 6 processing code has a number of improvements in addition to the Level 2 improvements from which it is built.

Significant changes include:

- Level 3 support products, which contain profile data at 100 vertical levels;
- a "TqJoint" grid, which contains gridded data for a common set of temperature and water vapor observations; and
- water vapor and trace gas products that are now reported both as layer and level quantities.

For additional information and to access to these data, visit:

disc.sci.gsfc.nasa.gov/datareleases/aqua-airs-version-6-level-3.

ESTO: Benefitting Earth Science through Technology

Andrea Martin, Earth Science Technology Office, andrea.s.martin@nasa.gov

Through flexible, science-driven, competitive solicitations, ESTO-funded technologies have supported many Earth observing measurements. Today, the portfolio of ESTO projects consists of nearly 700 active and completed tasks.

Satellites, airborne missions, and complex computer models all require advanced technologies to collect and process Earth observing data to increase our understanding of system phenomena. Demand for more, newer, and higher-quality Earth observations requires smaller, lighter, more-advanced remote-sensing tools as well as advanced data and computing systems. To meet these demands, NASA's Earth Science Division created the Earth Science Technology Office (ESTO). Along with the other ESD programs[1], ESTO is helping to ensure that quality Earth science data are being collected and used for a more-complete understanding of the planet.

ESTO was established in 1998 to manage the development of technologically advanced, reliable, and cost-effective components, instruments, and information systems that would help NASA meet its science objectives. Through flexible, science-driven, competitive solicitations, ESTO-funded technologies have supported Earth observing measurements, as well as some space science activities and commercial applications. Today, the portfolio of ESTO projects consists of nearly 700 active and completed tasks. These projects represent work at over 100 different government institutions, universities, and private corporations. More than 37% of "graduated" ESTO technologies have been infused into Earth-observing spaceborne and airborne missions, operational modeling systems and information networks, commercial uses, and other NASA purposes outside of the Earth sciences. An additional 43% of projects have a path identified for possible infusion.

ESTO employs an end-to-end approach to technology development. The investment strategies are planned carefully by working closely with the science and technology community to identify upcoming technology needs that could help fill mission and science requirements. The needs are met through competitive peer-reviewed solicitations to fund varying projects with differing methods to best address community requirements. ESTO often funds several projects that work toward advancing a similar technology or meeting a specific mission's requirements. Funding competing technologies ensures that future Earth science objectives can and will be met. ESTO assesses the maturity of funded technologies and leverages investments by working closely with other NASA programs and partnering with federal agencies, academia, and industry. Therefore, the end products—based on needs of the community and selected competitively and completed collaboratively—have a high likelihood of being infused into future missions and measurements.

The ESTO projects are managed through two main program areas: *Observation Technology* and *Information Technology*. A pilot program area, In-Space Validation of Earth Science Technologies (InVEST), was recently added to validate observation and/or information technologies from space. The Observation Technology Program is responsible for the Instrument Incubator Program (IIP), which supports projects that develop technologies that lead to Earth-observing instruments, sensors, and systems; and the Advanced Component Technologies (ACT) program, which supports projects that develop components and instrument subsystems. The Information Technology Program manages the Advanced Information Systems Technology (AIST) projects that process, archive, access, and visualize Earth-science data for the benefit of the Earth-science community. Each of these components will be discussed in more detail here.

Observation Technology Program

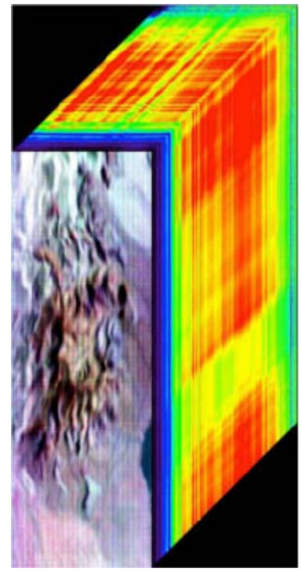
Instrument Incubator Program

The IIP fosters the development and assessment of innovative ground-based, aircraft-based, and engineering demonstrations of new remote sensing instrumentation.

[1] Other ESD programs include Flight, Research and Analysis, and Applied Sciences.

Projects managed by IIP develop smaller, lighter instruments, which often take less time to build and cost less than the development of traditional instrumentation. By funding new instruments very early in their life cycle and then demonstrating their performance, IIP projects that are slated for space-based applications typically encounter less development risk, lower cost, and reduced schedule overruns when the instrumentation for satellites is developed.

Most of the current IIP investments are directly tied to the needs of NASA's Decadal Survey missions[2]. For example, the upcoming Hyperspectral Infrared Imager (HyspIRI) mission will require a spaceborne thermal infrared (TIR) imager as one of its two major instruments[3]. To demonstrate a possible TIR technology prior to mission implementation, ESTO funded Principal Investigator (PI) **Simon Hook** [NASA/Jet Propulsion Laboratory (JPL)] to develop and test the airborne Hyperspectral Thermal Emission Spectrometer (HyTES). Airborne HyTES data can be used to help HyspIRI scientists and engineers determine the optimal band locations for the TIR instrument on the spaceborne platform and can be used by the science community to gather high-resolution surface temperature and emissivity measurements. These data can be used for a variety of studies, including observing thermal and gas anomalies from volcanoes. Measurements over different land-surface types and emissions such as sulfur dioxide, methane, and ammonia could also be used to help determine whether HyTES could be useful for in-depth gas studies.



This spectral cube represents HyTES-collected data over Cuprite, NV—a mining district commonly used for hyperspectral imaging testing and calibration/validation flights—on July 20, 2012. The data were collected as part of HyTES' first flights. The three bands [150 (10.08 µm), 100 (9.17 µm), and 58 (8.41 µm)] are displayed as red, green, and blue respectively as an image cube. **Image credit: Simon Hook**

In addition, HyTES offers both high spatial and spectral resolution—a feature not found on current NASA hyperspectral thermal imagers. This compact instrument collects data in the spectral range of 7.5–12 µm. The success of the first test flights indicates that HyTES could be a valuable resource for both refining the measurement requirements for HyspIRI's TIR instrument and for the science community to use in various ecosystem and natural-disaster applications. Since the initial flights[4] HyTES team members have been working on various improvements to the instrument. HyTES will fly again in coming months to acquire new data over selected sites to assess these improvements and evaluate the data's suitability for science studies.

Advanced Component Technologies

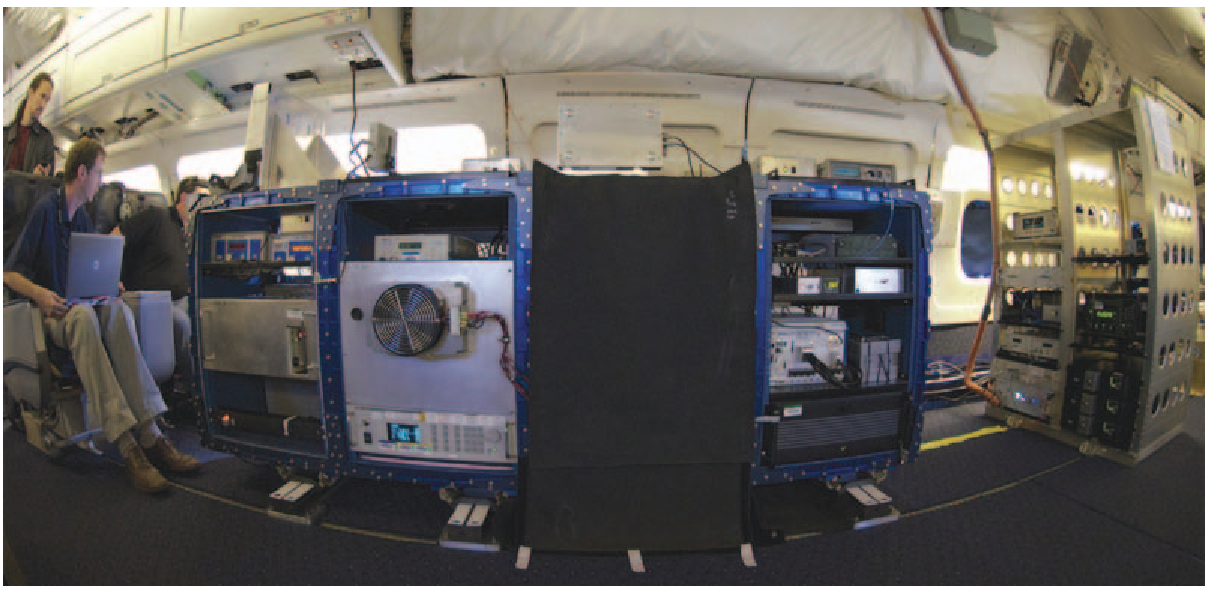
The ACT program funds and manages subsystem-level technologies that can include altimeters, control systems, or laser systems used for lidar. The ACT also develops new ways to perform measurements and to process data products to expand research and application capabilities. Some technologies developed under ACT are directly infused into mission designs by flight projects, while others graduate to different programs, like IIP, for further development and testing.

The ACT program investments can offer answers to big questions with difficult solutions. For example, the proposed Active Sensing of CO_2 Emissions over Nights, Days, and Seasons (ASCENDS) mission will need a high-power fiber-laser source to measure oxygen (O_2) from space. This measurement can be used to help determine the mixing ratio of carbon dioxide (CO_2) in the atmosphere. An ACT-managed project titled *Laser Remote Sensing of* O_2 *for Determination of* CO_2 *Mixing Ratio and Sensing of Climate Species*, led by PI **Jeremy Dobler** [ITT Exelis Geospatial Systems], is one ESTO project that has been tasked with developing the instrumentation and algorithms that could make O_2 measurements from space possible, leading to a more-complete picture of Earth's changing climate. Measurements like this will be key to the success of the planned ASCENDS mission.

[2] Following completion of the first Decadal Survey in 2007, the National Research Council prioritized 15 satellite missions to enable NASA to provide the public with ongoing information about global climate and climate change. To learn more about the program, visit: *nasascience.nasa.gov/earth-science/decadal-surveys*.
[3] To learn more about progress of plans for HyspIRI, see page 38 of this issue.
[4] HyTES had its first flight in the summer of 2012.

The mechanisms inherent to optical fibers set an upper limit on the achievable amplified power, so meeting the power and efficiency needed for ASCENDS' lidar is an extremely difficult task. This, however, is precisely the kind of technology development challenge that the ACT program can address.

Dobler's team is developing an *integrated path differential-absorption* (IPDA) lidar instrument to meet ASCENDS' requirements for measuring O_2. As part of the IPDA development effort, the team has developed the first high-power, narrow-spectral-linewidth fiber-laser source at a wavelength of 1262 nm—which corresponds to an O_2 absorption feature that can be used for spectroscopic lidar measurements. This achievement was made onboard a NASA DC-8 in 2011; however, the power of the amplifier was lower than the 5 W necessary to take these same measurements from space. Mechanisms inherent to optical fibers set an upper limit on the achievable amplified power, so meeting the power and efficiency needed for ASCENDS' lidar is an extremely difficult task. This, however, is precisely the kind of technology development challenge that the ACT program can address. The program is funding efforts to help develop fibers through various techniques, including doping phosphosilicate fibers with additional elements such as fluorine. These specialty fibers are under development and testing as part of a second ACT project; therefore, Dobler's team should be able to overcome the fiber power limitations to meet the requirements necessary to take O_2 measurements from space in the 1260 nm spectral band. This is an example of how ACT's investments in exploring various solutions for required component technology are helping to ensure that upcoming missions will be able to meet their measurement requirements.



Fisheye lens photo of CO_2 and O_2 components integrated on the NASA DC-8 aircraft, from 2011. **Image credit: Jeremy Dobler**

Information Technology Program

Advanced Information Systems Technology

The AIST identifies, develops, and demonstrates advanced information system technologies to increase the accessibility and utility of Earth science data, and to enable new science measurements and information products to be used by the scientific and applications communities. Typical AIST projects include modeling tools, sensor webs, data processors, and visualization tools. Some AIST projects augment existing tools—such as NASA's Land Information System (LIS) model.

Land-use and water-resource managers often make decisions that rely on information calculated by specialized computer models like LIS. A key feature of this modeling software is the ability to assimilate NASA land-surface observations into land-surface models. The conventional data assimilation approach used by LIS and other NASA data assimilation systems assumes that model state predictions are unbiased relative to the observations. As a result, additional techniques are needed to remove such systematic errors prior to incorporating Earth observations. The ESTO's AIST program has funded a project that addresses this issue by designing and implementing optimization and uncertainty modeling tools to enhance LIS. **Christa Peters-Lidard** [NASA's

Goddard Space Flight Center—*PI*] led the LIS-Optimization (LIS-OPT) and LIS-Uncertainty Estimation (LIS-UE) efforts, which added new infrastructure to LIS to augment existing data assimilation capabilities. The goal was to improve modeling using both parameter estimation and uncertainty estimation. The new LIS gives decision makers both improved environmental prediction and uncertainty information.

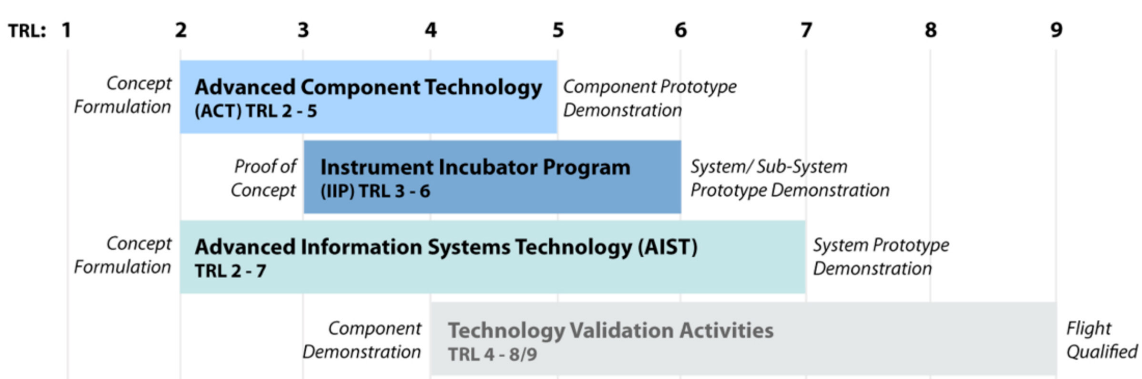
The project team conducted case studies and *observing system simulation experiments* (OSSEs) to compare the LIS outputs before and after the inclusion of LIS-OPT and LIS-UE. The first OSSE focused on using NASA observations to improve the values and uncertainty estimates of *soil hydraulic properties*—key land-surface model parameters. These improvements translated to improved land-surface model predictions and reduced uncertainty. Because one case study (Walnut Gulch, AZ) covered data from a limited time, this OSSE highlighted the observation that LIS-OPT used in conjunction with LIS-UE could be a useful strategy for mitigating bias prior to assimilating datasets from newly launched missions. This could mean that new mission data, like the soil moisture data that will be collected by the upcoming Soil Moisture Active Passive (SMAP) mission[5], will be available for parameter refinement soon after they are collected—as opposed to waiting for a longer data record to accrue. This is just one example of an AIST project that is leading to major improvements in increasing the reliability of modeling NASA-generated Earth-observation data.

The new Land Information System (LIS) gives decision makers both improved environmental prediction and uncertainty information.

Technology Readiness Levels

The progress of ESTO projects is monitored through the use of Technology Readiness Levels (TRLs). This nine-point scale helps to categorize emerging technologies in terms of their readiness for infusion, with TRL 9 being "mission proven" though successful mission operations on either ground or in space. While the definitions of TRLs are slightly different for software than for the more-common hardware definitions, they remain successful at accurately articulating and reflecting the stages of the software development process.

On average, ESTO projects enter ESTO management at approximately TRL 3. At this level a proof of concept has been met. The ESTO projects "graduate" at a TRL 6, meaning that a model or prototype has been demonstrated in a relevant end-to-end environment. To see a full list of TRLs and a brief description of each level for both hardware and software, visit: *esto.nasa.gov/technologists_trl.html*.



This graph depicts where ESTO investments generally fall on the TRL scale by program area. **Image credit**: ESTO

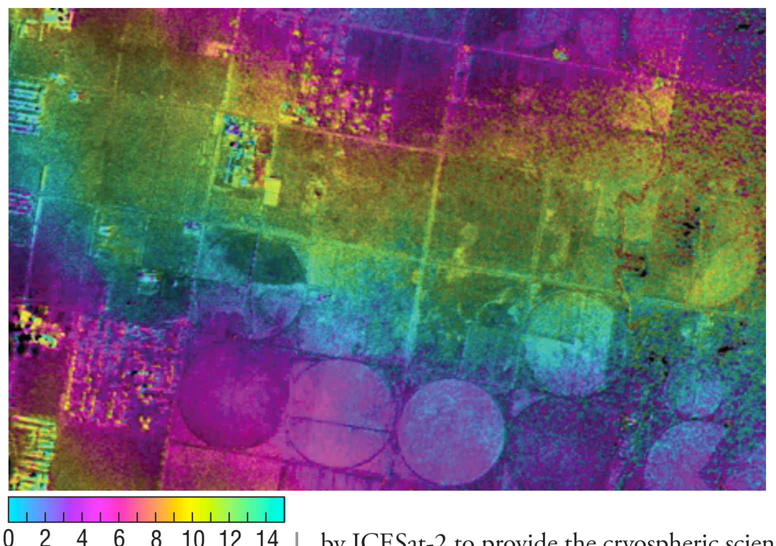
ESTO's Partnership Program

The ESTO often works closely with partner groups within NASA's ESD on technologies of shared interest. For instance, ESTO has teamed with the Research and Analysis (R&A) program to integrate existing instruments—often instruments that were first funded as part of an IIP solicitation—into platforms managed by NASA's Airborne Science Program. The Airborne Instrument Technology Transition (AITT) program

[5] Read more about the progress of SMAP calibration/validation efforts in preparation for its 2014 launch on page 32 of this issue.

for example—funded by R&A and managed in conjunction with ESTO—provides campaign-ready airborne instrumentation that can participate in field experiments, evaluates satellite instrument concepts, and provides calibration and validation of spaceborne instruments.

Consequently, AITT projects support many of NASA's Decadal Survey Earth-observing missions—one example being the second Ice, Cloud, and land Elevation Satellite (ICESat-2) that will collect valuable measurements on ice sheets and sea ice. The concern is that undersampling, especially in glacial areas, could lead to ice-volume estimation errors. Airborne instruments can help bridge these impeding data gaps. In 2009, as part of International Polar Year, a swath-mapping airborne sensor flew over Greenland, collecting data for high-resolution ice-surface topography maps to gain a clear picture of ice volume in that area. **Delwyn Moller** [Remote Sensing Solutions—*PI*], led an AITT-funded effort to take what was learned during that airborne campaign and develop an improved, permanently available, K_a-band Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR)-configured interferometer. The instrument—named the Airborne Glacier and Land Ice Surface Topography Interferometer (GLISTIN-A)—has modified the International Polar Year interferometer that flew over Greenland with a new K_a-band up-and down-converter chain and a state-of-the-art solid-state power amplifier. These improvements will allow higher peak transmit power and the ability to *ping-pong,* a mode of operation that allows the antenna to alternately transmit and receive, which improves the vertical accuracy of data. The current configuration of GLISTIN-A is being transitioned for flight on the NASA Global Hawk (GLISTIN-H) where it will be able to provide quality data on ice topography in areas that are often deemed too remote for in-depth study. The information the interferometer collects will be able to complement the data collection by ICESat-2 to provide the cryospheric science community with data collection over areas in the polar regions, like some glacial areas, that might not be routinely sampled by satellite missions.



First-look at uncalibrated elevation data (in meters) obtained by GLISTIN-A over the Rosamond Lake area in Los Angeles County, CA, from an altitude of about 5.7 miles (~9.2 km). **Image credit: Delwyn Moller**

New and Future Programs

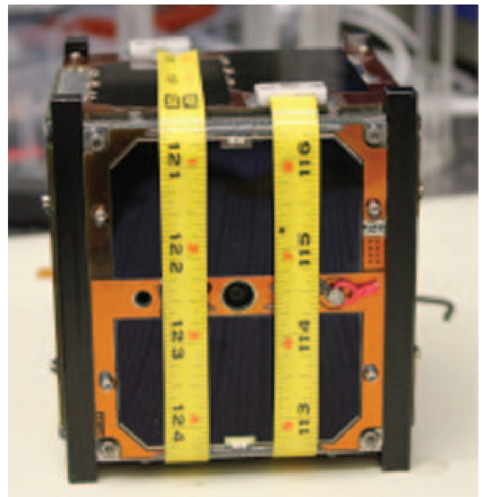
Beyond the challenges being addressed through Earth science technology research and development, other obstacles must be overcome to successfully implement emerging technologies in science missions and campaigns. Once a technology achieves its technical targets in the laboratory, the next step is to show that it can work as designed under real-world operating conditions. *Validation*, performed for airborne and spaceborne platforms, is a critical step in mitigating the risk associated with new technologies that have not been thoroughly tested and verified; this can be a source of mission delays and cost overruns. To mitigate these risks, ESTO is actively facilitating and pursuing opportunities to flight qualify various emerging technologies—such as instrument components and information systems—in relevant environments, through partnerships (like the AITT program described above), both within and outside of NASA. To date, over 70 ESTO technologies have been demonstrated onboard airplanes, uninhabited aerial vehicles, and high-altitude balloons.

The space environment, particularly, imposes harsh conditions on the components and systems of satellite missions that cannot be fully simulated in the confines of Earth's atmosphere. Therefore, instruments and components for spaceborne applications cannot be adequately validated on the ground or as part of an airborne system.

With the advances in small, low-cost "standard" satellites that can gain easy access to space, it possible to demonstrate and validate some hardware components and information systems. An example is *CubeSats*—10-cm (~4-in)-cube form factor platforms that are launched as secondary payloads on larger satellite missions. CubeSats are leading the way as a standard platform to cost-effectively launch and test new technologies. Costing as little as one-to-two million U.S. dollars, CubeSats are usually built and launched within 18 to 24 months from acceptance of the original concept proposal.

The ESTO recognizes the need for validation in the space environment and the possibilities CubeSats present, and has funded (for example) the development and launch of the Michigan Multipurpose Minisat (M^3), which carries the CubeSat Onboard Processing Validation Experiment (COVE) payload. COVE was developed to address the data-processing needs of future missions that are expected to collect higher-volume and higher-quality data. For example, the Multi-angle Spectropolarimetric Imager (MSPI), which is an IIP project (and a candidate for the Aerosol, Cloud, Ecosystems (ACE) mission concept) will produce 95 megabytes of data per second, per camera, for each of its nine cameras. However, there is currently no way to get that amount of raw data from space to the ground. One solution proposed by the COVE payload was to move the first stage of ground processing to onboard the satellite in a new radiation-hard-by-design *field-programmable gate array* (FPGA). This would reduce downlink requirements by two orders of magnitude. COVE, including the MSPI algorithm and the new FPGA, was launched on the M^3 CubeSat[6] in 2011. Access to space was enabled via the NASA Human Exploration and Operations Mission Directorate, CubeSat Launch Initiative.

M^3 CubeSat carrying COVE. **Image credit**: Michigan's Student Space Systems



In addition to M^3, ESTO is developing and implementing other CubeSat projects. For example, the GEOstationary Coastal and Air Pollution Events (GEO-CAPE) Read Out Integrated Circuit (ROIC) Flight Experiment [GRIFEX] project will verify the engineering and performance of an ACT-developed, all-digital, high-frame-rate readout integrated circuit for the GEO-CAPE mission concept. GRIFEX has been designed to meet the specific requirements of GEO-CAPE, but could also be used for other imaging instruments. The Intelligent Payload Flight Experiment (IPEX) will demonstrate the Intelligent Payload Module (IPM)—a candidate for the HyspIRI mission. The IPEX CubeSat will return low-latency data products via direct broadcast. IPM should reduce the HyspIRI raw data rate (in GBps) by a factor of at least twenty. IPEX and a second M^3 CubeSat will be launched in the fall of 2013 on a National Reconnaissance Office satellite mission as secondary payloads.

The IPEX CubeSat. **Image credit**: California Polytechnic State University

With the successful experiences of past and current CubeSat projects and the need to validate more technologies than the ones already funded, ESTO has initiated a new pilot program called In-Space Validation of Earth Science Technologies (InVEST). By developing a new program area, highly specialized validation projects can more appropriately be selected and managed. A request for information was released in 2011; the first InVEST solicitation was posted in the fall of 2012[7] through the NASA Research Opportunities in Space and Earth Sciences (ROSES). By validating Earth science technologies in space long before integration on an Earth-observing mission, the risks involved in developing successful Earth science missions will be reduced. Once validated, existing Earth science related technology is more ready for rapid infusion.

[6] M^3 was built by the University of Michigan's Student Space Systems Fabrication Laboratory. It was a secondary payload to the Suomi National Polar-orbiting Partnership spacecraft.
[7] Awards for the 2012 InVEST solicitation were announced on April 30, 2013. The four awards can be viewed at *esto.nasa.gov/files/solicitations/INVEST_12/ROSES2012_InVEST_awards.html*.

From top to bottom, the unique stacking technology for RTIMS: First layer of components added to the package; remaining layers assembled; pure epoxy resin molding; nickel and gold plating; and final tantalum shielding. **Image credit: Jeff Herath** [LaRC]

Infusion of ESTO Technologies

Over the course of 15 years of technology developments, advances, and validation, many ESTO technologies have been integrated into field campaigns, Earth-observing missions, planetary missions, or commercial applications. Many are fulfilling the roles for which they were intended and are making contributions to science and society. Some projects have even been infused into multiple platforms for various uses far outside their initial objective.

Field campaigns for example, are regular early adopters of ESTO technologies. Beginning in 2009 the NASA IceBridge campaign has collected data on the internal layering and bottom topography of ice sheets using the Pathfinder Advanced Radar Ice Sounder (PARIS)—a high-altitude sounding radar. During the summer of 2012 the Two-Column Aerosol Project, led by the U.S. Department of Energy, used the ESTO-funded High Spectral Resolution LIDAR (HSRL-2) to help quantify aerosol properties, radiation, and cloud characteristics.

The ESTO's AIST program funded the Radiation Tolerant Intelligent Memory Stack (RTIMS) project at NASA's Langley Research Center (LaRC) as part of a 2002 solicitation. The memory module was initially developed for Earth-observing missions at geostationary and low-Earth orbits for real-time data processing in harsh space environments. What made RTIMS useful for spaceborne applications also made it useful for data processing in the hard radiation environment found on Mars. RTIMS is now operating on the Chemistry and Camera (ChemCam) instrument on the Mars Rover Curiosity. As part of ChemCam, RTIMS controls the firing of the laser beam that pulverizes rock for analysis, data acquisition and buffering, and communication with the Rover Computer Element. RTIMS is small enough to easily fit in the palm of your hand, yet it safeguards ChemCam's observations with novel radiation-shielding and radiation-mitigation technologies. The memory module also employs a radiation event detection system and triple-redundant digital memory, plus in-flight reconfigurability. These features all enable RTIMS to overcome both hardware and software errors and to adapt to changing mission conditions.

Curiosity is not the only instantiation where RTIMS is proving itself useful. Astrium, a European aerospace company, is integrating RTIMS into a communications satellite, and is evaluating it for other projects. Another partner in the development of RTIMS, 3D Plus Inc., has also commercialized modules, which can be used for any application where radiation-tolerant memory and computing are needed.

Sometimes, ESTO projects aren't directly infused into a NASA mission, but can still contribute to the technology used for Earth observations. The recently selected Earth Venture Instrument—the Tropospheric Emissions: Monitoring of Pollution (TEMPO[8])—was influenced by early technology investments made by ESTO. The TEMPO mission will provide a spectrometer that collects ultraviolet and visible data on major pollutants including ozone, nitrogen dioxide, sulfur dioxide, formaldehyde, and aerosols from 22,000 miles (~35,405 km) above Earth's equator. Two IIP projects have played—and will continue to play—a pivotal role in the development and operation of TEMPO. The Geostationary Spectrograph for Earth and Atmospheric Science Applications (GeoSpec) and Geostationary Trace Gas and Aerosol Sensor Optimization (GeoTASO) projects have been critical in bringing together the TEMPO instrument

[8] Learn about TEMPO in the March–April issue of *The Earth Observer* [**Volume 25**, **Issue 2**, pp. 10-15].

and science team members as they worked to develop airborne prototype spectrometers and the algorithms required to measure air quality.

The work being completed on GeoTASO, an airborne spectrometer for trace gas and aerosol studies, is also contributing to development of the TEMPO sensor design. The algorithm sensitivities related to the GeoTASO sensor design will help match the TEMPO sensor design to its specific algorithm needs. In addition, GeoTASO's reconfigurable sensor will test algorithm performance over a range of parameters such as optimal spectral sampling. Polarization sensitivities will help dictate TEMPO's sensor parameter choices. Algorithm refinement for GeoTASO will also ensure that when TEMPO is launched, the retrieval algorithms will be readily and reliably applicable to the data collected. When TEMPO is fully operational, the airborne GeoTASO instrument will be available for use as a possible validation tool for the TEMPO mission.

Conclusion

While ESTO is a relatively young program in NASA's history, it has made great strides over the past 15 years in managing technology development that have enabled new science measurements, faster data processing, lighter payloads, and development of greatly improved models. By tying the needs of the science and user communities to the technologies developed, ESTO has been able to anticipate the needs of current and future NASA Earth-observing missions and objectives. The smaller, lighter, more-cost-effective, and improved technologies have had far-reaching impact—not just in terms of addressing the needs of the Earth Science Division Flight program, but also with regard to meeting the needs of planetary missions like Curiosity, and commercial applications for remote sensing.

In coming years, ESTO will continue to actively manage technology development for NASA's Earth science community as the program also begins addressing the need for in-space validation. The well-tested technological advances to come will help to ensure a bright future for Earth observing missions, science measurements, and discovery in general.

In coming years, ESTO will continue to actively manage technology development for NASA's Earth science community, as the program also begins addressing the need for in-space validation. The well-tested technological advances to come will help to ensure a bright future for Earth and planetary missions, science measurements, and discovery in general.

To learn more about ESTO, visit: *esto.nasa.gov*. You can follow ESTO on Twitter: *@NASAESTO*. ■

Share Your Field Experience on NASA's Earth Observatory

Do you have a NASA-related field campaign or other field work coming up this year? Would you like to publicize it on one of NASA's most popular Earth science websites? For the past four years the Earth Observatory has supported blogging for over 15 field campaigns ranging from ocean cruises in the North Atlantic and Galapagos, to airborne campaigns over California and the Arctic, to examinations of glaciers in Antarctica and the taiga in Siberia.

Publishing on the Earth Observatory puts your campaign in front of nearly 70,000 weekly email subscribers and thousands of other readers via RSS and social media. We provide the blogging system and promotion; you provide your experiences and photos. For example, **Lora Koenig** [NASA's Goddard Space Flight Center (GSFC)] has just returned from Greenland where she has been on the ice studying the aquifer. You can read about her experience at *earthobservatory.nasa.gov/blogs/fromthefield/category/greenland-aquifer-expedition*.

To learn more about the site, visit: *Notes from the Field* on the Earth Observatory at *earthobservatory.nasa.gov/blogs/fromthefield*.

Let the Earth Observatory help you communicate your science to the public. For more information or to ask questions, email **Kevin Ward** [GSFC—*Earth Observatory Manager*] at *kevin.a.ward@nasa.gov*.

2012 CLARREO Science Definition Team Meeting Summary

Rosemary Baize, NASA's Langley Research Center, rosemary.r.baize@nasa.gov
Bruce Wielicki, NASA's Langley Research Center, bruce.a.wielicki@nasa.gov
Amber Richards, NASA's Langley Research Center/Science Systems and Applications, Inc., amber.l.richards@nasa.gov

The fourth meeting of the Climate Absolute Radiance and Refractivity Observatory (CLARREO) Science Definition Team (SDT) was held at the University of Colorado Laboratory for Atmospheric and Space Physics (LASP) in Boulder, CO, October 16-18, 2012. CLARREO SDT members from LASP hosted the meeting and provided the team with a tour of their instrument calibration/test facilities and on-site Mission Operations and Science Operations Centers.

David Young [NASA's Langley Research Center (LaRC)—*Project Scientist*] welcomed attendees to the meeting and highlighted the team's recent publications—e.g., 31 journal papers published from pre-formulation studies (20 in 2012 alone); 9 journal papers submitted or in review; and 24 more in preparation. He emphasized the important role the science team is playing in creating and disseminating new scientific knowledge related to the CLARREO mission. Young also noted progress made by the SDT, working in coordination with engineers, to identify an alternative International Space Station (ISS) mission concept that optimizes science, cost, and risk. Finally, he reviewed options being discussed with NASA Headquarters (HQ) for continuing the work of the SDT past April 2013—the current expiration date. **Ken Jucks** [NASA HQ—*Program Scientist*] noted that the CLARREO science objectives remain a high priority for NASA's Earth science community, and thanked the team for their publications. Following Young and Jucks, members of the SDT provided updates on their CLARREO-specific activities since the last meeting in Hampton, VA in May 2012.

The technical portion of the meeting highlighted the accomplishments made by the SDT in advancing the CLARREO-related science goals over the past six months. Members of the SDT delivered talks on the infrared (IR), reflected solar (RS), and Global Navigation Satellite System–Radio Occultation (GNSS-RO) instruments, as well as special topics presentations[1] during the two-and-a-half-day meeting. Presentations focused primarily on investigations of the information content of CLARREO measurements; studies of the use of CLARREO data for reference intercalibration of other sensors; studies related to alternative, cost-effective mission architectures; and progress reports on continuing technology demonstrations of achieving on-orbit absolute accuracy verification of the IR and RS spectrometers. The meeting agenda and many of the presentations can be viewed at *clarreo.larc.nasa.gov* by pulling down the *Workshops and Conferences* tab. A few of the highlights from the presentations are given below, listed by major topic area.

Alternative Implementation Options: Venture Class and International Space Station

The CLARREO team continues to explore multiple options for getting instruments to make key CLARREO observations into orbit. Several concepts were competitively pursued in 2011 and 2012 through the Venture Class Program. The Far-Infrared Explorer (FIREX) and Zeus IR spectrometers and the Earth Climate Hyperspectral Observatory (ECHO) RS spectrometer were all proposed under Earth Venture-2 (EV-2) solicitation. The Zeus and ECHO instrument concepts were also proposed under the Earth Venture Instrument (EVI-1) call. While none of these were ultimately selected, all three CLARREO-related instruments were rated as being technically mature [i.e., having a Technology Readiness Level (TRL) of 6 or greater[2]]. **Hank Revercomb** [University of Wisconsin-Madison (UW)] provided a debrief of the EV-2 review for the Zeus proposal and shared lessons learned for the future. The other option being considered is deploying CLARREO-related instruments on the ISS. **Barry Dunn** [LaRC] presented results from a study showing that the combined CLARREO IR and RS instruments could be readily accommodated on the Japanese Experiment Module Exposed Facility. The ISS implementation option has also shown the ability to obtain 73% of CLARREO baseline mission science value at approximately 40% of the Mission Concept Review defined cost.

Technology Demonstrations of CLARREO Climate Change Accuracy for IR and RS Spectra

Dave Johnson [LaRC] and **Kurt Thome** [NASA's Goddard Space Flight Center (GSFC)] provided updates on the CLARREO IR and RS Calibration Demonstration Systems (CDS), respectively. Construction of both instruments was successfully completed in 2012. In 2013 the CDS efforts will focus on verifying that CLARREO-level accuracies have been

[1] These topics include a framework for multi-instrument intercalibration (MIIC) operations, CLARREO accommodations on the Japanese Experiment Module on the ISS, and the economic value of improved climate observations.

[2] TRL is a measure that the Earth Science Technology Office (ESTO) uses to assess how *mature*—ready for use in space—a given technology is. To learn more, see *ESTO: Benefitting Earth Science through Technology* on page 22 of this issue.

achieved with full error budgets and having undergone National Institute of Standards and Technology (NIST) reviews. In addition, comparisons are planned with the UW IR spectrometer—giving CLARREO the type of independent verification that is the hallmark of accurate metrology. UW is also advancing vacuum and vibration qualification testing to achieve TRL 6 on both component and instrument system levels. **Greg Kopp** [LASP] provided an overview of the Hyperspectral Imager for Climate Science (HYSICS) instrument. Recently, LASP demonstrated better than 0.2% accuracy within one standard deviation (1-σ) in the ratio of reflected (outgoing) to incoming solar radiation, achieving CLARREO-level accuracies. LASP is planning a high-altitude balloon flight in August 2013, which will demonstrate HYSICS under realistic flight conditions (i.e., TRL-7).

Use of CLARREO Spectrometers for Reference Intercalibration of Other Sensors in Orbit

Costy Lukashin [LaRC] discussed a practical demonstration of the CLARREO RS instrument using the ISS as a platform for intercalibration of other satellite instruments, thereby improving the accuracy of the Earth-observing system. Estimates of the number of samples useful for intercalibration using Sun-synchronous spacecraft (i.e., JPSS and MetOP[3]) revealed that the ISS orbit is well suited for performing intercalibration. **Lukashin** and **Dave Doelling** [LaRC] described the *multi-instrument intercalibration* (MIIC) framework, a streamlined approach for teams responsible for calibration and validation of target instrument data. Intercalibration events from multiple spacecraft for a given temporal window are automatically calculated from the specified sampling criteria and orbit crossings. For each event intercalibration algorithms are executed on remote servers using Open-source Project for Network Access Protocol (OPeNDAP[4]) server-side functions prior to delivery of the data to the instrument teams for further analysis. The approach has been shown to save months of effort that would have been required to download extraneous data; it also reduces local processing.

Climate Observing System Simulation Experiments

The SDT meeting highlighted several pioneering new methods for *observing system simulation experiments* (OSSEs) for climate observations. **Dan Feldman** [University of California-Berkeley] provided an overview of the first combined IR/RS OSSE—completed during 2012. The operational OSSE is being used to conduct observational tests for climate model response and to assess the utility of CLARREO-like hyperspectral measurements, e.g., using shorter times to detect climate change trends. These measurements will provide a benchmark against which future measurements can be compared to detect and attribute climate change signals. Working in coordination with **Xu Liu** [LaRC] and **Zhonghai Jin** [Science Systems and Applications, Inc. (SSAI)], the Berkeley team (Dan Feldman and Bill Collins) has incorporated a new reflected solar Principle Component Radiative Transfer Model (PCRTM) to speed up the OSSEs by a factor of 30. In 2013 the team is moving toward incorporation of Coupled Model Intercomparison Project Phase 5 (CMIP5) datasets to provide OSSEs with varying climate sensitivity. **Zhonghai Jin** presented a cloud-based probability distribution function method, which provides a simple, fast, and effective option in obtaining the mean spectral reflectance in large climate domains using large volume of instantaneous satellite data. This new approach was applied to Moderate Resolution Imaging Spectroradiometer/Clouds and the Earth's Radiant Energy System (MODIS/CERES) data; the simulated spectral reflectance agreed well with Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY) measurements.

Spectral Climate Change Fingerprints and Radio Occultation

A key CLARREO innovation is to add a new type of climate-change detection: "fingerprints" of IR and RS spectra. **Yolanda Roberts** [LASP] and **Peter Pilewskie** [LASP] described advances in this area, utilizing *principle component analysis* (PCA) to determine how the information content in short-wave hyperspectral radiances can be used to study changes in the Earth's climate. Results showed that six principal components could be used to explain 99% of the variance between the CLARREO climate OSSEs and SCIAMACHY datasets. Moreover, the PCA analysis helped identify key spectral patterns (e.g., water vapor, clouds, surface albedo, and sea ice). **Seiji Kato** [LaRC], **Xianglei Huang** [University of Michigan], and **Yi Huang** [McGill University] provided advanced results from IR *fingerprinting* using data from the Atmospheric Infrared Sounder on NASA's Aqua platform, climate model simulations, and CLARREO OSSE experiments. **Bill Smith** [UW] and **Larrabee Strow** [University of Maryland, Baltimore County] showed new climate-focused retrieval strategies for IR spectra. **Chi Ao** [NASA/Jet Propulsion Laboratory] showed results aimed at understanding and improving RO profile retrievals near the marine boundary layer, especially for climate applications.

Economic Value Studies

Bruce Wielicki [LaRC—*Mission Scientist*] summarized steps taken to combine the CLARREO *Science*

continued on page 43

[3] The Joint Polar Satellite System is a joint NASA–NOAA endeavor; MetOp-A and -B are the European Organization for the Exploitation of Meteorological Satellite's (EUMETSAT) operational meteorology satellites.

[4] OPeNDAP is a common data transport protocol used by Earth-science researchers and practitioners.

SMAP Calibration/Validation Workshop

Thomas Jackson, U.S. Department of Agriculture, Agricultural Research Service, tom.jackson@ars.usda.gov
Peggy O'Neill, NASA's Goddard Space Flight Center, peggy.e.oneill@nasa.gov
Eni Njoku, NASA/Jet Propulsion Laboratory, California Institute of Technology, eni.g.njoku@jpl.nasa.gov

Introduction

NASA's Soil Moisture Active Passive (SMAP) mission is on schedule for launch in October 2014. SMAP will provide high-resolution, frequent-revisit, global mapping of soil moisture and freeze/thaw state that will enable a variety of hydrology, climate, and carbon-cycle science objectives and meteorological, agricultural, environmental, and ecological applications that are expected to have practical benefits for society—see *SMAP at a Glance* on page 36 to learn more. As with other space missions, the SMAP Project is required to implement a calibration/validation (cal/val) program to assess and minimize random errors and spatial and temporal biases in the soil moisture and freeze/thaw estimates, and demonstrate that SMAP retrievals meet the stated science requirements of the mission.

Up until now SMAP cal/val activities have primarily focused on prelaunch activities, seeking to insure that means are in place to fulfill mission objectives (e.g., acquiring and processing data with which to calibrate, test, and improve models and algorithms used to retrieve SMAP science data products). Now, however, with launch less than two years away, the focus has shifted to preparing for postlaunch activities, where the emphasis will be on validating the accuracies of the SMAP science data products. A number of different methodologies have been proposed as part of the cal/val process—from the use of external calibration targets for the Level 1 (L1) instrument data (e.g., cold sky, ocean, forests, Antarctic scenes) to a combination of *in situ*, field campaign, satellite, and model data for the L2-4 geophysical data products—see **Table 1**.

SMAP will be the first of the missions proposed in the Earth Science Decadal Survey to launch. NASA Headquarters (HQ) has required that SMAP deliver fully calibrated instrument data and retrieved geophysical products to the SMAP Distributed Active Archive Centers (DAACs) for archive and public access within 15 months after launch (which is within 12 months of the start of SMAP routine science operations). SMAP radar data will be delivered to the Alaska Satellite Facility (ASF), while all other SMAP data will be sent to the National Snow and Ice Data Center (NSIDC). **Table 2** lists the SMAP baseline mission data products. *Beta versions* of L2-4 data products and validated L1 data products are due nine months after launch—see **Figure 1.** Due to the compressed timeline for the cal/val phase of the SMAP mission, it is essential that all the cal/val tools and methodologies are tested and in place by the launch date.

Table 1. SMAP Level 2-4 data product validation methodologies.

Methodology	Role	Constraints	Resolution
Core Validation Sites	Accurate estimates of products at matching scales for a limited set of conditions	• *In situ* sensor calibration • Limited number of sites	• *In situ* testbed • Cal/val partners
Sparse Networks	One point in the grid cell for a wide range of conditions	• *In situ* sensor calibration • Up-scaling • Limited number of sites	• *In situ* testbed • Scaling methods • Cal/val partners
Satellite Products	Estimates over a very wide range of conditions at matching scales	• Validation • Comparability • Continuity	• Validation studies • Distribution matching
Model Products	Estimates over a very wide range of conditions at matching scales	• Validation • Comparability	• Validation studies • Distribution matching
Field Campaigns	Detailed estimates for a very limited set of conditions	• Resources • Schedule conflicts	• Simulators • Partnerships

Table 2. SMAP baseline mission data products.

Product	Description	Gridding (Resolution)	Latency†	Data
L1A_Radiometer	Radiometer data in time-order	–	12 hrs	**Instrument**
L1A_Radar	Radar data in time-order	–	12 hrs	
L1B_TB	Radiometer brightness temperature T_B in time-order	(36 x 47 km)	12 hrs	
L1B_S0_LoRes	Low-resolution radar σ_O in time-order	(5 x 30 km)	12 hrs	
L1C_S0_HiRes	High-resolution radar σ_O in half-orbits	1 km (1-3 km)*	12 hrs	
L1C_TB	Radiometer T_B in half-orbits	36 km	12 hrs	
L2_SM_A	Soil moisture (radar)	3 km	24 hrs	**Science** (Half-Orbit)
L2_SM_P	Soil moisture (radiometer)	36 km	24 hrs	
L2_SM_AP	Soil moisture (radar + radiometer)	9 km	24 hrs	
L3 FT_A	Freeze/thaw state (radar)	3 km	50 hrs	**Science** (Daily Composite)
L3_SM_A	Soil moisture (radar)	3 km	50 hrs	
S3_SM_P	Soil moisture (radiometer)	36 km	50 hrs	
L3_SM_AP	Soil moisture (radar + radiometer)	9 km	50 hrs	
L4_SM	Soil moisture (surface and root zone)	9 km	7 days	**Science** Value Added
L4_C	Carbon net ecosystem (NEE)	9 km	14 days	

* Over outer 70% of swath.
† The SMAP project will make a best effort to reduce the data latencies beyond those shown in this table.

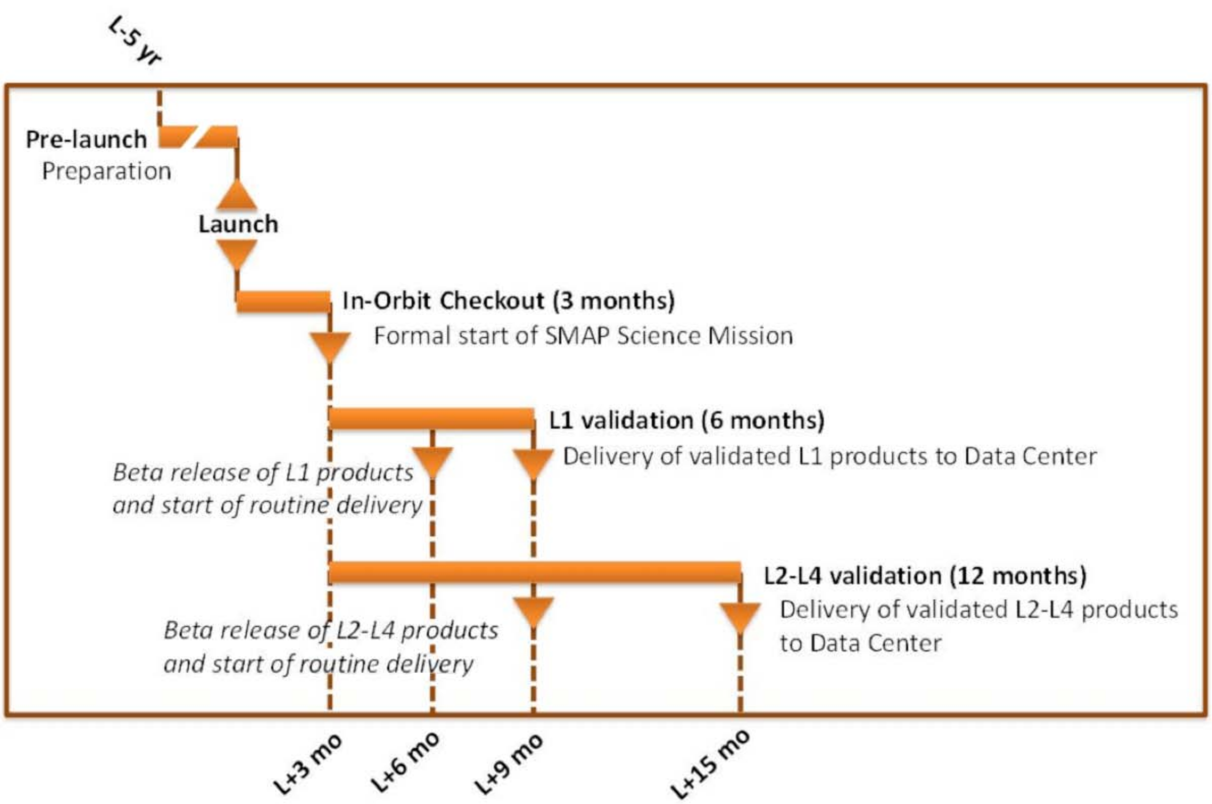


Figure 1. SMAP science data validation and delivery timeline.

Workshop Overview

To solicit science community input, the SMAP Project held its third community Cal/Val Workshop in Oxnard, CA, November 14-16, 2012. Participants included over 80 scientists and students, many of them from the SMAP Cal/Val Working Group—which is open to any interested individuals. For more detailed information on SMAP Working Groups, visit: *smap.jpl.nasa.gov/science/wgroups*. Summary information and presentations from the Cal/Val Workshop are posted at *smap.jpl.nasa.gov/news/index.cfm?FuseAction=ShowNews&NewsID=121.*

Workshop presentation topics included:

- An overview of project status;
- results of a formal panel review of the SMAP cal/val plan;
- L1 instrument data calibration;
- L2-4 retrieval algorithms and their cal/val requirements;
- ground-based and aircraft field campaigns with SMAP simulators;
- descriptions of core and sparse *in situ* measurement networks; and
- methods for upscaling sparse or point data to SMAP resolutions.

SMAP has been developing its *in situ* validation resources by establishing global Cal/Val Partners[1].

[1] To learn more about SMAP Cal/Val Partners, visit: *smap.jpl.nasa.gov/science/Validation/solicitations*.

Eni Njoku [NASA/Jet Propulsion Laboratory (JPL)—*SMAP Project Scientist*] and **Tom Jackson** [U.S. Department of Agriculture (USDA)—*SMAP Cal/Val Working Group Chair*] welcomed workshop participants on the first day. **Image credit: Alicia Joseph** [NASA's Goddard Space Flight Center (GSFC)]

The Partners provide data to SMAP on a no-exchange-of-funds basis in return for access to SMAP products during the early-mission cal/val phase. The Partners were selected primarily in response to a *Dear Colleague Letter* released by NASA HQ. **Figure 2** shows that a concerted effort has been made to distribute the SMAP cal/val sites spatially around the world and across a variety of major biomes. During the workshop, **Tom Jackson** [U.S. Department of Agriculture (USDA)—*SMAP Cal/Val Working Group Chair*] discussed how the process of becoming a Cal/Val Partner is being formalized and how new cal/val sites can be added. A poster session following this discussion provided an opportunity for Cal/Val Partners to present more information about their individual sites and measurement plans.

A major point of discussion at the workshop involved the design and implementation of *cal/val rehearsal*

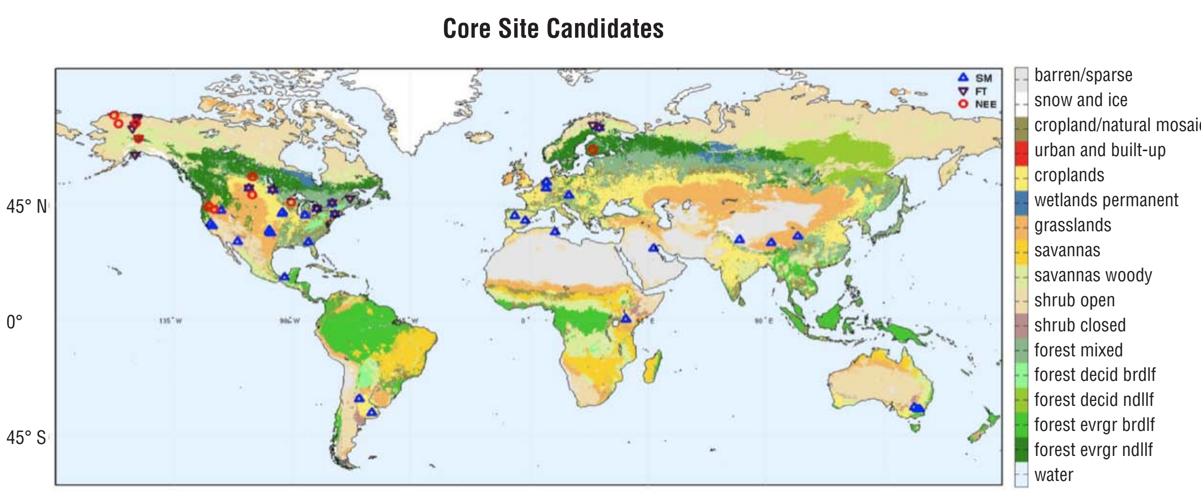


Figure 2. This map shows the global distribution of Cal/Val Partners (excluding the sparse networks), superimposed on a background image of land-cover types which are listed in the legend along the right side of the map. **Image credit: Andreas Colliander** [JPL]

Workshop participants interacting during the poster session.
Image credit: Peggy O'Neill [GSFC]

Installation of *in situ* sensors at MOISST.
Image credit: Michael Cosh [USDA]

Tom Jackson discussing results with **Narendra Das** [JPL].
Image credit: Alicia Joseph [GSFC]

Demonstration of the portable COSMOS Rover system.
Image credit: Alicia Joseph

campaigns[2] prior to the launch of SMAP, which is NASA's first soil moisture mission. The workshop consensus was that there should be two phases to a cal/val rehearsal campaign. The first phase will take place in summer 2013 and focus on the delivery and quality control of *in situ* ground truth data from SMAP's global Cal/Val Partners as well as the development of essential cal/val tools. The second phase will take place in summer 2014 and will be an end-to-end test of the SMAP science data processing system and cal/val tools.

The final day of the workshop began with a review of the Marena Oklahoma In Situ Sensor Testbed (MOISST)—a SMAP initiative to provide a basis for the integration and cross-calibration of the diverse *in situ* soil moisture measurement sensors and resources that will be used in cal/val activities—see top right photo above. This testbed includes instrumentation from many operational networks. Following the MOISST discussion, updates were presented on the Plate Boundary Observatories, Climate Reference Network, and the COsmic-ray Soil Moisture Observing System (COSMOS[3]) network, as well as a demonstration of a portable version of COSMOS—called the COSMOS Rover [see bottom right photo above].

The workshop concluded with discussion and identification of action items to:

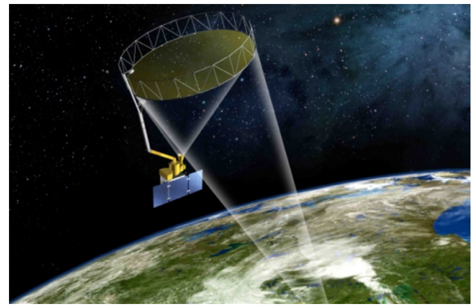
- define absolute calibration reference standards and procedures to be used for SMAP L1 radiometer and radar calibration;
- define the postlaunch *SMAP Validation Experiments* airborne campaigns planned for 2015 or 2016 (SMAPVEX15 or SMAPVEX16), including science objectives, site selection, desired airborne instruments, aircraft flight timing/duration, and a data analysis plan;
- complete agreements with Cal/Val Partners;

[2] Pre-launch cal/val rehearsal campaigns will ensure that the methodologies and tools are in place for the operational phase of the mission.

[3] COSMOS is a National Science Foundation (NSF)-supported project to measure soil moisture on the horizontal scale of hectometers and depths of decimeters using cosmic-ray neutrons. For more information, visit: *cosmos.hwr.arizona.edu*.

SMAP at a Glance

Orbit Information



Type:	Near-polar, Sun-synchronous
Altitude (average geodetic):	685 km (~425.6 mi) Equator-crossing altitude
Equatorial Crossing Time:	18:00 hrs (6:00 PM local mean solar time; ascending node)
Inclination:	98.12°
Period:	98.5 min
Repeat Cycle:	8 days (exact orbit repeat)
Revisit	2-3 days

Spacecraft Specs

The SMAP spacecraft has been built in-house at NASA/Jet Propulsion Laboratory (JPL), leveraging avionics and power electronics derived from previous planetary missions. The spacecraft is designed to accommodate the unique needs of a large spinning instrument in a compact package that can fit within a small launch vehicle's fairing. The spacecraft structure is of aluminum construction and includes large reaction wheels that provide momentum compensation for the large, spinning 6-m- (~20-ft) diameter mesh reflector. The spacecraft has an S-band transponder to accommodate ground-based Doppler tracking for orbit determination rather than using the Global Positioning System (GPS) because the large spinning instrument antenna blocks GPS visibility. The solar array uses three fixed panels that are mounted to the spacecraft structure. The spacecraft design puts bounds on how the solar array, the large instrument reflector, and boom assembly are deployed, and the release of the spun instrument launch lock to allow the instrument to rotate. The spacecraft must also accommodate the large data volume generated by the SMAP synthetic aperture radar.

Length:	1.5 x 0.9 x 0.9 m (4.9 x 3 x 3 ft), spacecraft bus only
Mass:	1150 kg (~2535 lbs), including propellant and instrument
Power:	1450 W
Downlinks:	S-Band (satellite control and monitoring), X-Band (science data)
Design Life:	3 years

Launch Details

Date:	Late 2014
Location:	Vandenberg Air Force Base, Lompoc, CA
Vehicle:	United Launch Alliance Delta II *7320-10C*

Instrument Summary

The instrument consists of an L-band radiometer and an L-band synthetic aperture radar (unfocused), sharing a rotating 6-m (~20-ft) mesh reflector and boom assembly. The spun instrument rotates continuously at rates from 13 to 14.6 rpm; antenna pointing is at a constant incidence angle of 40°. This arrangement produces a 1000-km (~621-mi) measurement swath that efficiently enables global coverage every two-to-three days. Radiometer antenna beam efficiency is > 87%, with an antenna temperature precision of < 0.5 K and a reflector emissivity of < 0.0035. Radar antenna gain is 35.5 dBi with a half-power beamwidth of 2.8°.

The 1.413-GHz radiometer is mounted on the spun-instrument platform (on the zenith-pointing spacecraft deck) to reduce losses between the instrument feed and the radiometer. The radiometer design mitigates radio frequency (RF) interference, and will acquire measurements in four channels [vertical (V) and horizontal (H) polarization, and third and fourth Stokes parameters[1]], with a brightness temperature accuracy requirement of 1.3 K. The radiometer's spatial resolution is approximately 40 km (~25 mi) (real aperture).The fixed 1.26-GHz radar is mounted to the interior of the anti-Sun spacecraft panel (providing a good thermal field of view of deep space) to reduce spin momentum. The radar will acquire measurements in VV, HH, and HV[2] polarization channels, and uses various techniques to mitigate RF interference, e.g., frequency hopping. The radar has 1-3 km (~0.6-1.9 mi) spatial resolution over the outer 70% of the swath; its transmit power of 500 W is provided by a solid-state high-power amplifier, with a 9% duty cycle.

[1] Stokes parameters represent the polarization state of electromagnetic radiation.

[2] A radar transmits microwave radiation and measures the *backscatter* off a distant object—or radar cross section. The SMAP radar measures *polarized* radiation; each channel transmits and receives radiation in different orientations. HH stands for Horizontal Transmit, Horizontal Receive; VV stands for Vertical Transmit, Vertical Receive; and HV stands for Horizontal Transmit, Vertical Receive. The first two are copolarized; the third is cross polarized.

- decide on a subset of Cal/Val Partners to be designated as Core Validation Sites (CVS) to verify overall mission accuracy metrics;
- develop a "Rehearsal Plan" document for Phase I of the mission, based on discussions at the workshop;
- work with the European Space Agency's Soil Moisture and Ocean Salinity (SMOS) mission and NASA's Aquarius mission to converge on a reference standard for land calibration (warm brightness temperature), which will be extrapolated from the conventional cold sky/ocean/Antarctic calibration targets; and
- publish definitions of SMAP mission validation metrics.

All workshop presentations have been uploaded to the SMAP website at *smap.jpl.nasa.gov/science/workshops/CalVal3WkshpPres*. The next SMAP Cal/Val Workshop will be held on November 5-7, 2013, following the planned summer cal/val rehearsal campaign. ■

Kent Kellogg [JPL—*SMAP Project Manager*] and **Diane Evans** [JPL—*Director for Earth Science and Technology*] were pleased with the workshop presentations, discussions, and proposed actions. **Image credit: Alicia Joseph**

NASA Water Vapor Project–MEaSUREs Dataset Release

The Atmospheric Science Data Center (ASDC) at NASA's Langley Research Center, in collaboration with the NASA Water Vapor Project–Making Earth System Data Records for Use in Research Environments (MEaSUREs) [NVAP-M] team, announce the release the following datasets:

- NVAP-M: Climate
- NVAP-M: Weather
- NVAP-M: Ocean

NVAP-M water vapor datasets comprise a combination of retrievals from the Atmospheric Infrared Sounder (AIRS) and the Special Sensor Microwave/Imager (SSM/I), radiosonde observations, High Resolution Infrared Sounder (HIRS) profiles, and Global Positioning System (GPS) observations. These datasets span 22 years (1988–2009) and contain total and precipitable water vapor from four layers.

The following are distinguishing features of the NVAP-M dataset:

- Global (land and ocean) data coverage;
- consistent, intercalibrated data sources;
- consistent, peer-reviewed algorithms;
- new data sources; and
- a three-tiered production format suitable for a variety of users.

The MEaSURES program creates stable, community-accepted Earth System Data Records (ESDRs) for a variety of geophysical time series, and is responsible for reanalysis and extension of NVAP-M data.

The datasets can be accessed from the ASDC at *eosweb.larc.nasa.gov/content/nvap-m*.

HyspIRI Science and Application Workshop Summary

Simon Hook, NASA/Jet Propulsion Laboratory, simon.j.hook@jpl.nasa.gov

Introduction

NASA's Hyperspectral Infrared Imager (HyspIRI) mission will observe the world's ecosystems and provide critical information on natural disasters such as volcanoes, wildfires, and drought. It will provide a benchmark on the state of the world's ecosystems against which future changes can be assessed, as the instruments will be capable of identifying vegetation type and health. The mission was recommended for implementation by the 2007 report from the U.S. National Research Council: *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond*[1].

To address its objectives, HyspIRI's instrumentation manifest includes a visible-to-short-wave-infrared (VSWIR) imaging spectrometer that covers the range 380–2500 nm in 10-nm contiguous bands, and a multispectral imager that covers the range from 3–12 μm with 8 discrete bands across the mid- and thermal-IR (TIR) portion of the spectrum. Both instruments have a spatial resolution of 60 m (~197 ft) at nadir. The VSWIR instrument will have a revisit time of 19 days; the TIR instrument will have a revisit time of 5 days. HyspIRI also includes an Intelligent Payload Module (IPM) that will enable a subset of the data to be processed onboard the satellite and downlinked to the ground in near-realtime.

Meeting Overview

Approximately 190 scientists attended the fifth annual HyspIRI Science and Applications Workshop, held October 16-18, 2012, in Washington, DC.

The three-day workshop provided an open forum to present the mission's observational requirements and to assess its anticipated impact on scientific and operational applications. Participants had the opportunity to obtain feedback from the broader scientific community on the mission concept and to participate in a half-day session on HyspIRI-related science applications. There was a special session on coastal and inland water studies and how HyspIRI complements missions under development to look at deeper oceans.

Owing to the depth and breadth of information provided at the workshop, only an upper-level summary will be provided here. The full workshop agenda, presentations, and speakers list are available at *hyspiri.jpl.nasa.gov/documents/2012-science-workshop*.

Day 1

Michael Freilich [NASA Headquarters (HQ)—*Earth Science Division Director*], **Jack Kaye** [NASA HQ—*Associate Director for Research, Earth Science Division*], and **Woody Turner** [NASA HQ—*Biological Diversity Program Manager*], provided the Headquarters perspective on the mission and how it fits into the "bigger picture" at NASA. In addition to discussing details specific to HyspIRI, they discussed the mission in the context of NASA's other Earth observing missions, the processes by which *Decadal Survey* missions (e.g., HyspIRI) were selected, and the steps involved in the mission development process. They also discussed how NASA's Science, Applied Sciences, and Technology programs contributed to the overall mission.

Dave Schimel [NASA/Jet Propulsion Laboratory (JPL)], **Dar Roberts** [University of Santa Barbara], **Michael Ramsey** [University of Pittsburgh], **Tom Painter** [JPL], and **Phil Dennison** [University of Utah] followed with presentations that highlighted the critical importance of HyspIRI science and applications. They discussed the use of HyspIRI data for ecosystem and volcano studies and some of the airborne precursor instrument development activities.

Steve Volz [HQ—*Associate Director for Flight Programs, Earth Science Division*] provided an update of NASA flight programs. **Carl Bruce** [JPL], **Marc Foote** [JPL] and **Dan Mandl** [NASA's Goddard Space Flight Center (GSFC)], provided updates on the two HyspIRI instruments (VSWIR, TIR) and the IPM. **Charles Norton** [JPL/Earth Science Technology Office (ESTO)] provided a description of ESTO activities in support of HyspIRI.

Simon Hook and **Robert Green** [JPL], rounded out the first day with presentations describing the Level-1 requirements[2] for the HyspIRI mission. Their presentation provided an opportunity for the community to fully understand the objectives for the mission. As with previous workshops, the community fully endorsed the requirements.

Day 2

The day's focus was on science applications and included a special session on the potential of HyspIRI data for studying coastal and inland waters—intended to provide key information not provided by the lower-spatial resolution missions designed to study deep oceans (e.g., Aqua). **Lawrence Friedl** [HQ—*Associate Director for Applied Sciences, Earth Science Division*] opened the second day with a presentation focusing on the NASA Applications Program. Many of the day's talks focused on applications of HyspIRI to operational uses. As there were over 30 technical presentations, individual presenters are not described here; full details,

[1] The report is also known as the Earth Science Decadal Survey and can be found online at *www.nap.edu/catalog.php?record_id=13405*.

[2] *Level-1 Requirements* represent project deliverables to NASA and the community.

Fifth annual HyspIRI Science and Application Workshop participants.

however, are available from the HyspIRI website—provided earlier in this article. These talks covered a wide range of topics and included updates from the studies funded by NASA solicitations, and updates on the key science questions that HyspIRI will address. The science questions were developed in conjunction with the Science Study Group, a group of scientists appointed by NASA to help guide the mission and to ensure that the measurements are of maximum benefit.

Day 3

The final day included discussions of related missions, partnership opportunities, and future plans. Of particular interest was the discussion of the HyspIRI Airborne Campaign[3]. As part of this preparatory airborne activity, NASA will fly the Airborne Visible Infrared Imaging Spectrometer (AVIRIS) and the MODIS/ASTER[4] Airborne Simulator [MASTER] instruments on its ER-2 high-altitude aircraft to collect datasets in concert with other instruments for precursor science and applications research. These data will be used for HyspIRI-related science studies, to support HyspIRI mission development, and to prepare the community for HyspIRI-enabled science and applications research.

Woody Turner convened a wrap-up session, commenting that not only was the workshop a wonderful series of talks on the utility of VSWIR imaging spectrometer data and multispectral TIR imagery, but—more importantly—a demonstration of the fundamental ground-breaking science that could be performed by the combined capability provided by using both instruments. Further, the workshop clearly demonstrated the value of the data for use in operational systems.

Turner concluded by providing more details on the HyspIRI Airborne Campaign, which will provide simulation data from the Sierras to the coastal zone of California. He noted that the project would ensure that community would be able to evaluate the challenges of handling large datasets. While the airborne data are limited to AVIRIS and MASTER, it is hoped that data from AVIRISng, PRISM, and HyTES[5] will also be made available over selected sites. A planning meeting was scheduled for November with first flights in March–April 2013[6]. The goal of the planning meeting was to decide on the areas that would be covered and to ensure that the necessary field measurements were made to maximize the usefulness of the data.

As with previous workshops, the Preliminary Level 1 mission requirements were reviewed with the community to make sure they would meet the science needs. This year 39 posters were presented at a special early evening session. Participants commented on the usefulness of this session as a way to find more detail about particular activities and for the opportunity to network. Participants were particularly appreciative of the excellent opportunity to present results in a more interactive environment and to network with colleagues.

Summary

The participants concluded that the HyspIRI mission would provide a significant new capability to study ecosystems and natural hazards at spatial scales relevant to human resource use and would be particularly valuable for climate related studies. It was clear that the measurement requirements could be achieved with the reference instrument design concepts and be implemented through the use of current technology. The participants strongly endorsed the need for the HyspIRI mission and felt the mission, as defined, would accomplish the intended science goals. There was significant enthusiasm about the HyspIRI preparatory airborne campaign and for obtaining data from the slated instrumentation suite.

The participants confirmed that the Draft Preliminary HyspIRI Mission Level 1 Requirements were achievable within the mission concept presented and would provide the necessary data to address the science questions identified for the mission.

The next HyspIRI Science and Applications Workshop will be held in October 15-17 in Pasadena, CA. ■

[3] The full name is HyspIRI Preparatory Airborne Activities and Associated Science and Applications Research; it is funded through the Research Opportunities in Space and Earth Science (ROSES) 2012 solicitation.

[4] MODIS is the Moderate Resolution Imaging Spectroradiometer; ASTER is the Advanced Spaceborne Thermal Emissions and Reflection Radiometer.

[5] AVIRISng is the Next Generation Airborne Visible/Infrared Imaging Spectrometer; PRISM is the Portable Remote Imaging Spectrometer; HyTES is the airborne Hyperspectral Thermal Emission Spectrometer.

[6] **UPDATE**: This campaign is currently underway; the first (spring 2013) series of flights completed in May.

First Light for ISERV Pathfinder, Space Station's Newest 'Eye' on Earth

Janet Anderson, NASA's Marshall Space Flight Center, janet.l.anderson@nasa.gov

EDITORS NOTE: This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

From the Earth-facing window of the International Space Station's (ISS) *Destiny* module, nearly 95% of the planet's populated area is visible during the station's orbit. This unique vantage point provides the opportunity to take photos of Earth from space. With the installation and activation of the ISS SERVIR[1] Environmental Research and Visualization System (ISERV), NASA will be able to provide even higher-resolution images of Earth.

This first-light image from ISERV, captured on February 16, shows the mouth of the Rio San Pablo in Veraguas, Panama, as it empties into the Gulf of Montijo. This wetland supports an important local fishery and provides habitat for many mammals and reptiles, as well as several species of nesting and wintering water birds. **Image credit:** NASA's Earth Observatory

The ISERV camera system's mission is to gain experience and expertise in automated data acquisition from the space station. ISERV is expected to provide useful images for disaster monitoring and assessment and environmental decision making. A system like ISERV could aid in delivering imagery and data to help officials in developing nations monitor impacts of disasters such as floods, landslides, and forest fires. Its images also could help decision makers address other environmental issues.

The instrument recently transmitted back its first images to scientists on Earth from its location in the Window Observational Research Facility (WORF[2]). ISERV is a commercial camera, telescope, and pointing system operated remotely from Earth by researchers at NASA's Marshall Space Flight Center (MSFC).

Acting on commands from the ground, ISERV can photograph specific areas of the Earth's surface as the ISS passes over them. The goal for ISERV is to help scientists gain operational experience and expertise and to influence the design of a more capable system for future ISS expeditions. The ISS provides researchers a unique opportunity to develop ISERV's capability by conducting global observations from space.

"ISERV's full potential is yet to be seen, but we hope ISERV or a successor will really make a difference in people's lives," said **Burgess Howell** [MSFC—*ISERV Principal Investigator*]. "For example, if an earthen dam gives way in Bhutan, we want to be able to show officials, via our images, where the bridge or a road is washed out, or where a power substation has been inundated. This kind of information is critical to focus and speed rescue efforts."

An operational system with ISERV's optical characteristics could, in many cases, acquire near-real-time images of areas on the ground and transmit them within hours of the event. This would provide information that could shape disaster relief decisions and possibly prevent loss of life or injuries.

"ISERV could become a tool to enhance and expand NASA's hazard and disasters work across the whole disaster management cycle," added **Frank Lindsay** [NASA Headquarters (HQ)—*Applied Sciences Disasters Program Manager*]. "The bottom line is that this camera opens up some opportunities we did not have before and clearly is a pathfinder for more assets on the space station for our applications."

ISERV's software maintains knowledge of the space station's exact location and attitude in orbit at any given moment. With this information, it calculates the next chance to view a particular area. If there's a good viewing opportunity, the SERVIR team will send instructions to the camera. ISERV will take a series of high-resolution

[1] SERVIR is a decision support system that allows NASA satellite data to be analyzed and applied to a variety of issues with practical benefits for society—including disaster management. The name is derived from the Spanish word for "to serve."
[2] The WORF was described in the October–November 2011 issue of *The Earth Observer* [**Volume 23**, **Issue 3**, pp. 25-27].

photographs of the area at rates of three to seven frames per second, totaling as many as 100 images per pass. "The camera's nominal resolution is about 10 ft (~3 m)," Howell explained. "That's about the size of a small car—and potentially valuable for disaster assessments."

At first, the instrument will be used only by SERVIR and its existing hubs in Mesoamerica, East Africa, and the Hindu Kush-Himalaya region. After proving itself, ISERV could be made available to the broader disaster-response community and the NASA science community.

The team is assessing how the geometry of the window affects its imagery, how much sunlight the instrument needs to capture clear images, how the atmosphere affects that clarity, and more. This characterization phase will last from several weeks to a few months. The exposure, time of day, and location, as well as the land cover (e.g., savannah, rivers, forests) and other characteristics will be documented, catalogued, and archived for every scene acquired.

continued on page 43

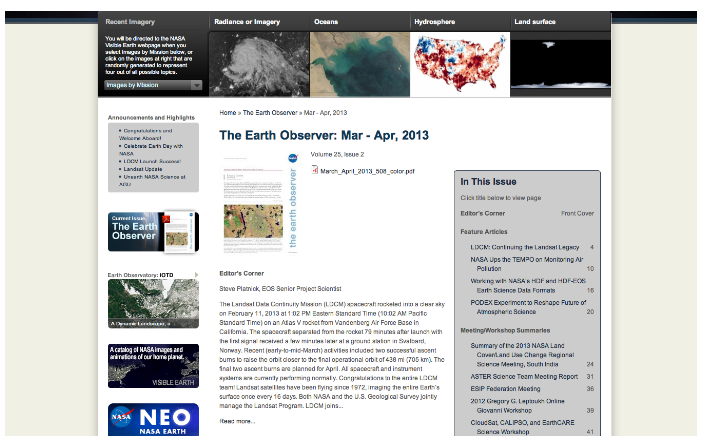
Announcing a New Look for the EOS Project Science Office Website

NASA's Earth Observing System Project Science Office (EOSPSO) recently launched an exciting redesign of the EOSPSO website at: *eospso.nasa.gov*. While the site has always included content that went beyond the original EOS missions, it now more strongly represents all of NASA's Earth-observing satellite missions (many of which are joint endeavors with other nations and/or agencies), along with other elements of NASA's Earth Science program.

Redesigned EOSPSO homepage.

The user interface has changed dramatically, with better content organization. Everything can now be more easily accessed via the main menu options listed across the top of the page. Potentially of interest to readers of this newsletter, *The Earth Observer Newsletter* menu option links to an index that dates back to the March-April 1999 issue. Color versions of the newsletter exist from January-February 2011 to present. A clickable table of contents, preview of the editorial, and PDF versions of the newsletter are available for each issue.

A standard *Google* search tool can be found in the top right corner of the page. Once a search is executed, users can categorize the results as "All results" or "Earth Observer" results. Clicking the "Earth Observer" option will focus the search to only The Earth Observer Newsletter pages.



The individual webpage for the March-April 2013 issue of *The Earth Observer* is displayed here.

In addition to the redesigned interface, new features include:

- an *Announcements and Highlights* blog;
- a color-coded sliding chart that displays mission status and timelines; and
- recent imagery and prominent links to the Earth Observatory, Visible Earth, and NASA Earth Observations websites.

We hope you enjoy the new site!

2013 Wintertime Arctic Sea Ice Maximum Fifth Lowest on Record

Maria-Jose Vinas, NASA's Goddard Space Flight Center, maria-jose.vinasgarcia@nasa.gov

EDITORS NOTE: This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

Last September, at the end of the northern hemisphere summer, the Arctic Ocean's icy cover shrank to its lowest extent on record, continuing a long-term trend and diminishing to about half the size of the average summertime extent from 1979 to 2000.

During the cold and dark of Arctic winter, sea ice refreezes and achieves its maximum extent, usually in late February or early March. According to a NASA analysis, this year the annual maximum extent was reached on February 28 and it was the fifth lowest sea ice winter extent in the past 35 years.

The new maximum—5.82 million mi^2 (15.09 million km^2)— is in line with a continuing trend in declining winter Arctic *sea ice extent*: nine of the ten smallest recorded maximums have occurred during the last decade. The 2013 winter extent is 144,402 mi^2 (374,000 km^2) below the average annual maximum extent for the last three decades.

"The Arctic region is in darkness during winter and the predominant type of radiation is longwave—or infrared—which is associated with greenhouse warming," said senior scientist **Joey Comiso** [NASA's Goddard Space Flight Center (GSFC)—*Cryospheric Sciences Program Principal Investigator*]. "A decline in the sea ice cover in winter is thus a manifestation of the effect of the increasing greenhouse gases on sea ice."

Satellite data retrieved since the late 1970s show that sea ice extent, which includes all areas of the Arctic Ocean where ice covers at least 15% of the ocean surface, is diminishing. This decline is occurring at a much faster pace in the summer than in the winter; in fact, some models predict that the Arctic Ocean could be ice-free in the summer in just a few decades.

The behavior of the winter sea ice maximum is not necessarily predictive of the following melt season. The record shows there are times when an unusually large maximum is followed by an unusually low minimum, and vice versa.

"You would think the two should be related, because if you have extensive maximum, that means you had an unusually cold winter and that the ice would have grown thicker than normal. And you would expect thicker ice to be more difficult to melt in the summer," Comiso said. "But it isn't as simple as that. You can have a lot of other forces that affect the ice cover in the summer, like the strong storm we got in August last year, which split a huge segment of ice that then got transported south to warmer waters, where it melted."

An image of the Arctic sea ice when it reached the annual maximum extent of 5.82 million mi^2 (15.09 million km^2) on February 28, 2013. **Image credit:** NASA

The sea ice maximum extent analysis produced at GSFC is compiled from passive microwave data from NASA's Nimbus-7 satellite and the U.S. Department of Defense's Defense Meteorological Satellite Program. The record, which began in November 1978, shows an overall downward trend of 2.1% per decade in the size of the maximum winter extent—a decline that accelerated after 2004.

The GSFC sea ice record is one of several analyses, along with those produced by the National Snow and Ice Data Center (NSIDC). The two institutions use slightly different methods in their sea ice tally, but overall, their trends show close agreement. NSIDC announced that Arctic sea ice reached its winter maximum on March 15, at an extent of 5.84 million mi^2 (15.13 million km^2)—a difference of less than half a percent compared to the NASA maximum extent.

Another measurement that allows researchers to analyze the evolution of the sea ice maximum is *sea ice area*. The measurement of area, as opposed to extent, discards regions of open water among ice floes and only tallies the parts of the Arctic Ocean that are completely covered by ice. The winter maximum area for 2013 was 5.53 million mi^2 (14.3 million km^2), also the fifth lowest since 1979.

While the extent of winter sea ice has trended downward at a less drastic rate than summer sea ice, the fraction of the sea ice cover that has survived at least two melt seasons remains much smaller than at the beginning of the satellite era. This older, thicker *multi-year ice*—which buttresses the ice cap against more severe melting in the summer—grew slightly this past winter and now covers 1.03 million mi^2 (2.67 million km^2), or about 39,000 mi^2 (101,010 km^2) more than last winter. The extent, however, is still less than half of what it was in the early 1980s.

"I think the multi-year ice cover will continue to decline in the upcoming years," Comiso said. "There's a little bit of oscillation, so there still might be a small gain in some years, but it continues to go down and before you know it we'll lose the multi-year ice altogether."

This winter, the negative phase of the Arctic Oscillation kept temperatures warmer than average in the northernmost latitudes. A series of storms in February and early March opened large cracks in the ice covering the Beaufort Sea along the northern coasts of Alaska and Canada, in an area of thin seasonal ice. The large cracks quickly froze over, but these new layers of thin ice might melt again now that the sun has re-appeared in the Arctic, which could split the ice pack into smaller ice floes.

"If you put a large chunk of ice in a glass of water, it is going to melt slowly, but if you break up the ice into small pieces, it will melt faster," said **Nathan Kurtz**, [GSFC—*Sea Ice Scientist*]. "If the ice pack breaks up like that and the melt season begins with smaller-sized floes, that could impact melt."

Kurtz will analyze data collected over the Beaufort Sea by NASA's Operation IceBridge—an airborne mission that is currently surveying Arctic sea ice and the Greenland ice sheet—to see if the sea ice in the cracked area was abnormally thin. ■

2012 CLARREO Science Definition Team Meeting Summary

continued from page 31

Value Matrix concept with economic *integrated assessment models* for estimating climate change impact costs across an Intergovernmental Panel on Climate Change (IPCC)-like frequency distribution of climate sensitivity. The research creates a framework for *value of information* calculations, placing a dollar value on uncertainty reduction. It provides a new approach to more rigorously understand the economic value of NASA's extensive range of climate science research.

David Young and **Bruce Wielicki** delivered a final wrap-up, followed by a team discussion of plans for publication of the science results and future collaborations among the team. The next meeting will be held in Hampton, VA in April 2013[5]. ■

[5] **UPDATE**: This meeting took place on April 10-12, 2013.

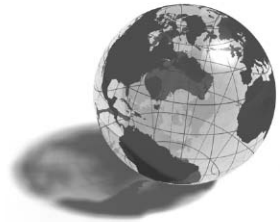
First Light for ISERV Pathfinder, Space Station's Newest 'Eye' on Earth

continued from page 41

SERVIR consists of a coordination office and student research laboratory at MSFC, active hubs in Kenya and Nepal, and a network affiliate in Panama. The coordination office develops application prototypes for the SERVIR and integrates new and relevant technologies from NASA and other scientific research partner organizations to meet the needs of host countries. SERVIR's primary technical work occurs at the hubs, which are staffed by local and regional experts from those countries. The hubs coordinate with other international and national organizations in their respective regions regarding climate change, environmental monitoring, disasters, weather, and mapping.

SERVIR, jointly funded by NASA and the U.S. Agency for International Development (USAID), operates within NASA's Earth Sciences Division at HQ. Four other NASA centers work with MSFC on the program, including Goddard Space Flight Center, Ames Research Center, Langley Research Center, and the Jet Propulsion Laboratory.

Watch video highlights of SERVIR's new camera system on the ISS at *servirglobal.net/Global/Articles/tabid/86/Article/1201/video-highlights-servirs-new-camera-system-on-iss.aspx*. ■

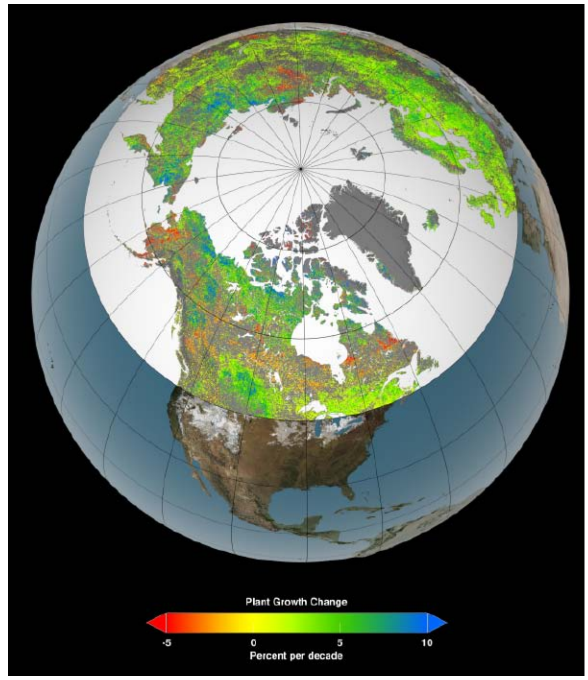


NASA Earth Science in the News

Patrick Lynch, NASA's Earth Science News Team, patrick.lynch@nasa.gov

***Visualized: First Photo Using ISS-mounted ISERV Pathfinder Zooms in on Panama,** March 7; *engadget.com*. The International Space Station (ISS) SERVIR Environmental Research and Visualization System [ISERV] Pathfinder—an imaging instrument that consists of a camera, telescope, and pointing system—was sent to the ISS in July 2012. The instrument was safely installed in the *Destiny* module on the ISS and captured its first image on February 16. The high-resolution image is of the Rio San Pablo, an ecological transition zone that's marked as a protected area by the National Environment Authority of Panama—see image on page 40.

Arctic Gets Greener as Climate Warms: NASA Study, March 11; *livescience.com*. Researchers report that higher temperatures and a longer growing season mean some of Earth's chilliest regions are looking increasingly green. According to a new study, the plant life found at northern latitudes today often looks like the vegetation researchers would have observed up to 430 mi (700 km) farther south in 1982. "It's like Winnipeg, Manitoba, moving to Minneapolis-Saint Paul, MN, in only 30 years," said **Compton Tucker** [NASA's Goddard Space Flight Center (GSFC)]. A team of university and NASA scientists looked at 30 years of satellite and land-surface data on vegetation growth from 45° N latitude to the Arctic Ocean. In this region large patches of lush vegetation now stretch over an area about the size of the continental U.S. and resemble what was found four-to-six latitude degrees to the south in 1982.



Of the 10 million mi^2 (26 million km^2) of northern vegetated lands, between 34 and 41% showed increases in plant growth (green and blue), 3 to 5% showed decreases in plant growth (orange and red), and 51 to 62% showed no changes (yellow) over the past 30 years. Satellite data in this image are from the Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS) instruments, which contribute to a vegetation index that allows researchers to track changes in plant growth over large areas. **Credit:** GSFC Scientific Visualization Studio

Large 2011 Arctic Ozone Hole Explained, March 11; *United Press International*. A combination of extremely cold temperatures, man-made chemicals, and a stagnant atmosphere caused a significant hole in the Arctic ozone layer in 2011. Although both the Earth's poles experience decreases in ozone during the winter, the ozone depletion over the Arctic tends to be milder and shorter-lived than that over Antarctica. Yet in 2011 ozone concentrations in the Arctic atmosphere were about 20% lower than average. While chlorine in the Arctic stratosphere and uncommon atmospheric conditions blocked wind-driven transport of ozone from the tropics, the main culprit was unusually low temperatures, said atmospheric scientist **Susan Strahan** [GSFC]. "You can safely say that 2011 was very atypical: In over 30 years of satellite records, we hadn't seen any time where it was this cold for this long," Strahan said.

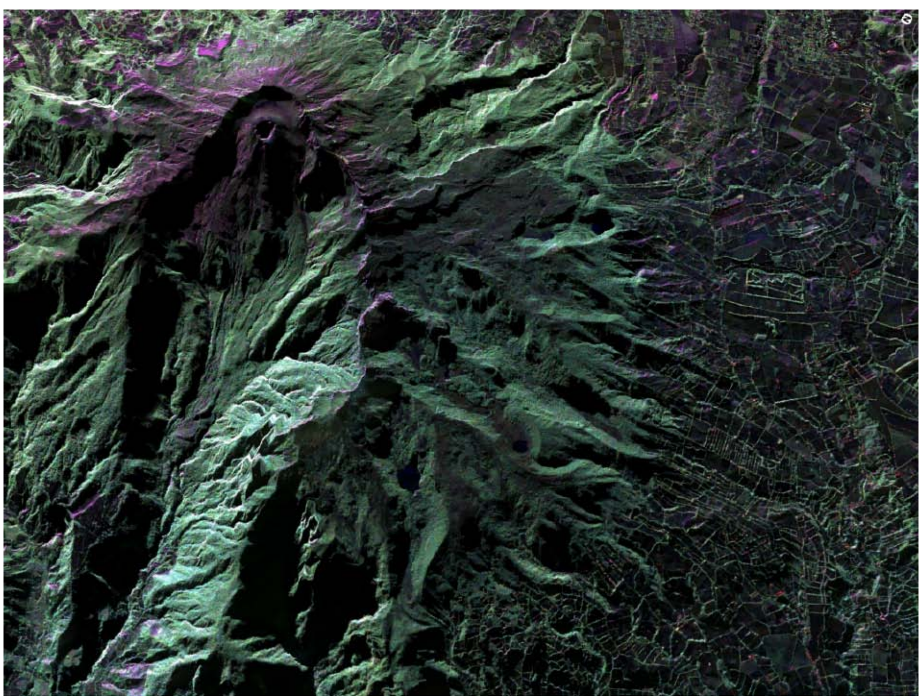
Landsat's First LDCM Images Show Rocky Mountains in Stunning Detail, March 22; *gizmag.com*. The first batch of images from the NASA-U.S. Geological Survey Landsat Data Continuity Mission (LDCM) are part of a three-month testing period, and show the meeting of the Great Plains with the Front Ranges of the Rocky Mountains in Wyoming and Colorado. It's already a pretty spectacular scene when viewed from space by instruments on other platforms, but the images from LDCM managed to enhance it even further.

NASA Sends Fleet of Small Drones to Inspect Noxious Volcano Plumes, April 2; *Los Angeles Times*. Last month a team of NASA researchers sent three repurposed military drones with special instruments into a sulfur dioxide plume emitted by Costa Rica's 10,500-ft (3200-m) Turrialba volcano. The team, led by principal investigator **David Pieri** [NASA/Jet Propulsion Laboratory (JPL)], launched 10 flights of the small, unmanned planes. The six-pound, twin-electric-engine planes, called Dragon Eyes, recorded video outside and inside the plume. Scientists think computer models derived from this study will contribute to safeguarding the National and International Airspace System, and will also improve global climate predictions and mitigate environmental hazards (e.g., sulfur dioxide volcanic smog, or *vog*) for people who live near volcanoes. The project was a collaboration among JPL and NASA's Ames Research Center and Wallops Flight Facility.

New Images from JPL's UAVSAR, the Radar that Sees through Trees, April 5; *Los Angeles Times*. In March, a manned, NASA-owned C-20A aircraft flew over the Americas carrying a powerful imaging radar system built and managed by the NASA/Jet Propulsion Laboratory (JPL). The radar's name is the Uninhabited Aerial Vehicle Synthetic Aperture Radar (UAVSAR). What's special about UAVSAR is that it uses microwaves to acquire data rather than the light from the Sun. That means the radar is not befuddled by cloud cover, or stopped by a thick leaf canopy in a rainforest. It can collect data through these traditional barriers, which can be especially helpful in the tropics. "If you looked at a picture of a rainforest on *Google Earth*, you would only see a bunch of trees, but we would see that these forests are flooded, and that gives a lot of additional information," said **Naiara Pinto** [JPL—*UAVSAR Science Coordinator*].

*See news story in this issue for more details.

Interested in getting your research out to the general public, educators, and the scientific community? Please contact ***Patrick Lynch*** *on NASA's Earth Science News Team at* ***patrick.lynch@nasa.gov*** *and let him know of upcoming journal articles, new satellite images, or conference presentations that you think would be of interest to the readership of* ***The Earth Observer***.



This image shows Colombia's highly active Galeras Volcano as acquired by UAVSAR on March 13, 2013. Galeras features a breached caldera and an active cone that produces numerous small-to-moderate explosive eruptions. UAVSAR will precisely fly the same flight path over the volcano in 2014. By comparing these camera-like images taken at different times, interferograms are generated that reveal changes in Earth's surface caused by volcanic deformation. **Credit:** NASA/Jet Propulsion Laboratory

NASA Science Mission Directorate – Science Education and Public Outreach Update

Theresa Schwerin, Institute for Global Environmental Strategies, theresa_schwerin@strategies.org
Morgan Woroner, Institute for Global Environmental Strategies, morgan_woroner@strategies.org

NASA Postdoctoral Fellowships

Deadline—July 1

The NASA Postdoctoral Program offers scientists and engineers unique opportunities to conduct research in space science, Earth science, aeronautics, exploration systems, lunar science, astrobiology, and astrophysics.

Awards: Annual stipends start at $53,500—with supplements for specific degree fields and high cost-of-living areas. There is an annual travel budget of $8000, a relocation allowance, and financial supplement for health insurance purchased through the program. Approximately 90 fellowships are awarded annually.

Eligibility: An applicant must be a U.S. citizen, lawful permanent resident, or foreign national eligible for J-1 status as a research scholar to apply. Applicants must have completed a Ph.D. or equivalent degree before beginning the fellowship, but may apply while completing the degree requirements. Fellowships are available to recent or senior-level Ph.D. recipients.

Fellowship positions are offered at several NASA centers. To obtain more information and to apply for this exciting opportunity, visit: *nasa.orau.org/postdoc*.

ESIP Teacher Workshop for Middle and High School Teachers

Date—July 9; Chapel Hill, NC

Middle- and high- school science teachers are invited to attend the 2013 Earth Science Information Partners (ESIP) Teacher Workshop on Tuesday, July 9, at the University of North Carolina at Chapel Hill. The workshop offers the opportunity to take an *iPad* on loan for an entire school year. The ESIP education committee invites regional science teachers to attend a one-day workshop, with an option to join ESIP members at an afternoon gathering at the North Carolina Museum of Natural History on Wednesday, July 10. The workshop theme will focus on Earth science education, with a strand on climate change education, featuring several hands-on sessions that demonstrate ways in which Earth science tools and data can be used in science classrooms. Space is limited to 20 teachers, so register now at *cimss.ssec.wisc.edu/teacherworkshop/esip*.

Presidential Awards for Excellence in Science, Mathematics, and Engineering Mentoring

Nominations Due—June 5

The Presidential Awards for Excellence in Science, Mathematics, and Engineering Mentoring (PAESMEM) were established by the White House to recognize U.S. citizens, permanent residents, and U.S. organizations that have demonstrated excellence in mentoring individuals from underrepresented groups in science, technology, engineering, and mathematics (STEM) education and career paths. Nominations, including self-nominations, are invited for individual and organizational PAESMEM awards. Each individual and organizational PAESMEM awardee will receive $10,000 and a commemorative presidential certificate to be awarded at a special ceremony in Washington, DC. Up to sixteen nominees will be awarded. For full rules and to submit nominations, visit: *1.usa.gov/15EHbqC*.

New Featured Products on NASA Wavelength

The NASA Wavelength home page at *nasawavelength.org* now offers a new round of forty featured products. This collection features educational resources from each of the NASA Science Mission Directorate's Education and Public Outreach Forums: astrophysics, Earth sciences, heliophysics, and planetary sciences. Resources cover a broad range of subject matter, and are appropriate for many different audiences.

NASA Solicitation: The GLOBE Program Implementation Office

NOIs Due—May 20; **Proposals Due**—July 19

The Global Learning and Observations to Benefit the Environment (GLOBE) Program is an important element of NASA's commitment to promoting STEM education among youth worldwide. The Earth Science Division of NASA's Science Mission Directorate solicits proposals for an organization or a consortium of organizations to host the GLOBE Implementation Office and to collaborate with NASA in implementing GLOBE, to strengthen programmatic support for GLOBE, and to enhance the value of GLOBE to its worldwide community of partners, students, teachers, and scientists. The GLOBE Implementation Office (GIO) shall perform functions related to GLOBE science, education, evaluation, and communication, as well as other functions necessary to support the GLOBE community. For more information and to view the full solicitation, visit: *bit.ly/ZRU1uz*. ■

EOS Science Calendar

June 10–12, 2013
ASTER Science Team Meeting, Tokyo, Japan.

October 7, 2013
Ocean Surface Topography Science Team Meeting, Boulder, CO.

October 15–17, 2013
HyspIRI Science and Applications Workshop, Pasadena, CA.

October 23–25, 2013
GRACE Science Team Meeting, Austin, TX.
www.csr.utexas.edu/grace/GSTM

November 5–7, 2013
SMAP Cal/Val Workshop, Oxnard, CA.
smap.jpl.nasa.gov/science/workshops

Global Change Calendar

June 24–28, 2013
AGU Chapman Conference - Crossing the Boundaries in Planetary Atmospheres: From Earth to Exoplanets, Annapolis, MD. *chapman.agu.org/planetaryatmospheres*

July 21–26, 2013
2013 International Geoscience and Remote Sensing Symposium, Melbourne, Australia. *www.igarss2013.org*

October 27–30, 2013
Geological Society of America, Denver, CO. *community.geosociety.org/2013AnnualMeeting/Home*

November 11–22, 2013
Conference of Parties (COP)-19, Warsaw, Poland.
www.cop19.org

December 9–13, 2013
American Geophysical Union, San Francisco, CA.
fallmeeting.agu.org/2013

Code 610
National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, MD 20771

PRSRT STD
Postage and Fees Paid
National Aeronautics and Space Administration
Permit 396

Official Business
Penalty for Private Use: $300

(affix mailing label here)

eos.nasa.gov

The Earth Observer

The Earth Observer is published by the EOS Project Science Office, Code 610, NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, telephone (301) 614-5561, FAX (301) 614-6530, and is available in color at *eospso.nasa.gov/earth-observer-archive*. Black and white hard copies can be obtained by writing to the above address.

Articles, contributions to the meeting calendar, and suggestions are welcomed. Contributions to the calendars should contain location, person to contact, telephone number, and e-mail address. Newsletter content is due on the weekday closest to the 15th of the month preceding the publication—e.g., December 15 for the January–February issue; February 15 for March–April, and so on.

To subscribe to *The Earth Observer*, or to change your mailing address, please call Cindy Trapp at (301) 614-5559, or send a message to *Cynthia.trapp-1@nasa.gov*, or write to the address above. If you would like to stop receiving a hard copy and be notified via email when future issues of *The Earth Observer* are available for download as a PDF, please send an email with the subject **"Go Green"** to *Cynthia.trapp-1@nasa.gov*. Your name and email address will then be added to an electronic distribution list and you will receive a bi-monthly email indicating that the next issue is available for download. If you change your mind, the email notification will provide an option for returning to the printed version.

The Earth Observer Staff

Executive Editor:	Alan B. Ward (alan.b.ward@nasa.gov)
Assistant/Technical Editors:	Heather H. Hanson (heather.h.hanson@nasa.gov) Mitchell K. Hobish (mkh@sciential.com)
Technical Editor:	Ernest Hilsenrath (hilsenrath@umbc.edu)
Design, Production:	Deborah McLean (deborah.f.mclean@nasa.gov)

Printed on Recycled Paper

NP-2013-2-006-GSFC