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Editor's Corner

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Continuing a busy year of launches for NASA's Earth Science Division,[1] the Ice, Cloud and land Elevation Satellite-2 (ICESat-2) successfully launched from Vandenberg Air Force Base in California at 6:02 AM PDT (9:02 AM EDT) on September 15, aboard a United Launch Alliance Delta II rocket—the final launch of the Delta II. About 75 minutes after launch, ground stations in Svalbard, Norway acquired signals from the spacecraft.

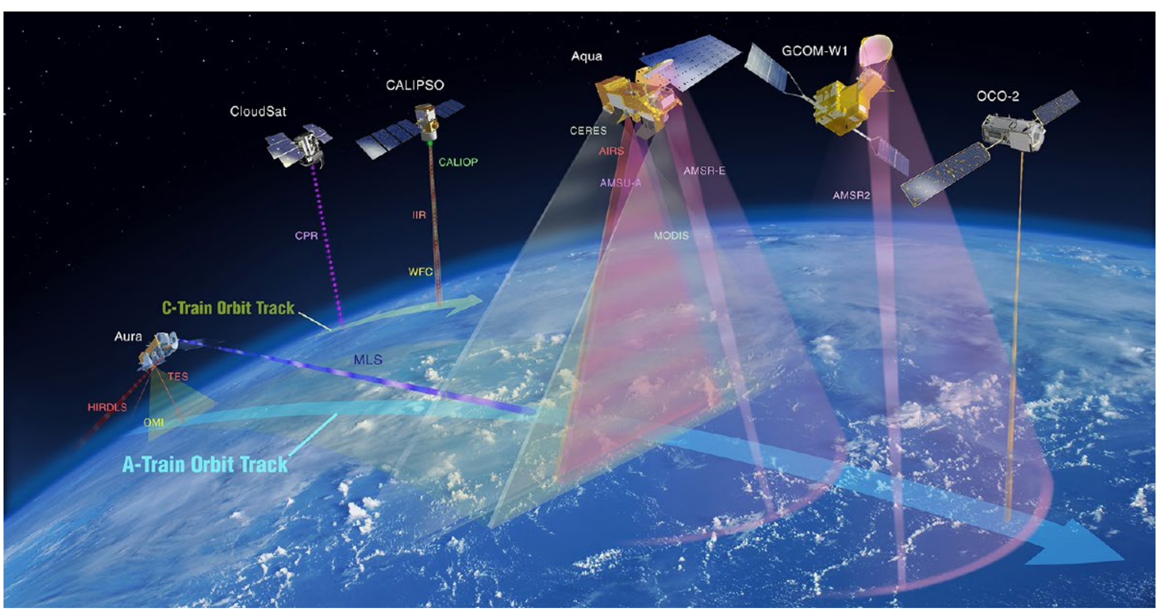
The Advanced Topographic Laser Altimeter System (ATLAS), the lone instrument on ICESat-2, successfully fired its laser on September 30 after the mission operations team completed testing of the spacecraft and opened the door protecting the optics. The primary science mission for ICESat-2 is to gather enough observations to estimate the annual height change of the Greenland and Antarctic ice sheets to within four millimeters.

ICESat-2 continues the record of ice height measurements started by NASA's original ICESat mission, which operated from 2003 to 2009. ICESat's ice height measurements were continued by the agency's annual Operation IceBridge airborne flights over the Arctic and Antarctic, which began in 2009 and continue to the present. The next round of deployments to Chile and Argentina are now underway, and will run through mid-November.

Data from ICESat-2 will be available to the public through the National Snow and Ice Data Center. Engineers at NASA Goddard built and tested the ATLAS instrument, and manage the ICESat-2 mission for NASA's Science Mission Directorate. Northrop Grumman designed and built the spacecraft bus, installed the instrument, and tested the completed satellite.

[1] So far this year, in addition to ICESat-2, NASA has launched GRACE-FO, ECOSTRESS, as well as NOAA's GOES-S (17) mission. The three previous 2018 launches have been discussed in the Editorials in the last three issues of *The Earth Observer* [**Volume 30**, **Issues 2, 3** and **4**]. GEDI is currently scheduled for a November 2018 launch.

continued on page 2



The international Afternoon Constellation includes the A-Train satellites (OCO-2, GCOM-W1, Aqua, and Aura) as well as the C-Train satellites (CALIPSO and CloudSat). **Image credit:** NASA

In This Issue

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

"With this mission we continue humankind's exploration of the remote polar regions of our planet and advance our understanding of how ongoing changes of Earth's ice cover at the poles and elsewhere will affect lives around the world, now and in the future," said **Thomas Zurbuchen** [NASA Headquarters (HQ)—*Associate Administrator of NASA's Science Mission Directorate*].

Turn to page 4 to learn more about the ICESat-2 mission and the ATLAS instrument.

We previously reported on the successful launch of ECOSTRESS, and its subsequent installation on the Japanese Experiment Module – Exposed Facility (JEM- EF) of the International Space Station.[2] The instrument began science operations on August 20, 2018 and has published its first images, including a map of California fires, and a map of urban heat in Los Angeles.[3] ECOSTRESS data is planned for public availability no later than six months after the start of science operations. An *early adopter program* will soon begin,[4] with early access to data. Interested users can sign up at the ECOSTRESS website at *https://ECOSTRESS.jpl.nasa.gov*.

The Earth Observer has also been following the details of CloudSat's departure from the A-Train, after technical issues that potentially affected the satellite's maneuvering capability. From September 13-20, CALIPSO executed a series of maneuvers to join CloudSat. As depicted in the front cover graphic, the international Afternoon Constellation now includes the A-Train satellites (OCO-2, GCOM-W1, Aqua, and Aura) as well as the C-Train satellites (CALIPSO and CloudSat). All of the satellites are in a sun-synchronous polar orbit, crossing the equator in an ascending (northbound) direction at about 1:30 PM local time. The C-Train, however, flies 16.5 km (~10 mi) below the A-Train and therefore follows a slightly different ground track, though it intersects the A-Train ground track about every 20 days, allowing for regular simultaneity between A-Train and C-Train instrument observations. CloudSat will resume its prior role of maintaining its position behind CALIPSO. The two satellites have an along-track separation of approximately 55 seconds. Since CALIPSO experiences about twice as much drag as CloudSat, CloudSat will conduct periodic orbit lower maneuvers to maintain a 100 second or less along-track offset with respect to CALIPSO. This positioning will be maintained within about +/-8.5 seconds, or about 4 km (~2.5 mi) of ground track offset, from CALIPSO. This is similar to the ground track offset while both satellites were in the A-Train.

With regard to future missions, NASA made five selections in response to its Earth Venture Suborbital-3

[2] See the Editorial of the July–August 2018 issue of *The Earth Observer* [**Volume 30**, **Issue 4**, p. 1] for details.
[3] To view these images, visit *https://climate.nasa.gov/news/2775/nasas-space-botanist-observes-california-nevada-wildfires and https://climate.nasa.gov/news/2802/ecostress-maps-las-hot-spots*.
[4] ECOSTRESS is following the template of *early adopters* set by other NASA missions, e.g., SMAP (*https://smap.jpl.nasa.gov/science/early-adopters*) and ICESat-2 (*https://icesat-2.gsfc.nasa.gov/early_adopters*).

(EVS-3) Announcement of Opportunity.[5] These new aircraft expeditions will begin taking flight in 2020. The winning investigations, their lead investigators, and research focus are as follows:

- ***Investigation of Microphysics and Precipitation for Atlantic-Coast-Threatening Snowstorms***—led by **Lynn McMurdie** [University of Washington]—focusing on intense snowstorms along the East Coast of the U.S.;
- ***Aerosol Cloud Meteorology Interactions over the Western Atlantic Experiment***—led by **Armin Sorooshian** [University of Arizona]—focusing on aerosols changing the properties of clouds over the Western Atlantic;
- ***Delta-X***—led by **Marc Simard** [JPL]—focusing on the Mississippi River Delta to study processes that maintain and build land in major river deltas threatened by rising seas;
- ***Dynamics and Chemistry of the Summer Stratosphere***—led by **Kenneth Bowman** [Texas A&M University] focusing on the impact of strong summer thunderstorms over North America on the stratosphere; and
- ***Submesoscale Ocean Dynamics and Vertical Transport Investigation***—led by **Thomas Farrar** [Woods Hole Oceanographic Institute]—focusing on an area 200 miles off the coast of San Francisco, CA, to examine the potentially large influence that small-scale ocean eddies have on the exchange of heat between the ocean and the atmosphere.

Congratulations to the PIs and their teams.[6]

Turning to personnel news, **Michael Freilich** [NASA HQ—*Director of the Earth Science Division (ESD)*] has announced he will retire from the agency in February 2019, after leading the ESD since 2006. Under his leadership, NASA Earth science evolved to a program that launches several missions each year while balancing orbital flight missions with research, applications, and technology development activities. The ESD also established new program elements, including the Earth Venture program of low-cost space and suborbital science missions, and leveraged the use of the International Space Station (ISS) as an Earth-observing platform. Having overseen 16 major mission and instrument launches and 8 CubeSat/small-satellite launches, Freilcih leaves a lasting legacy for his successor. I add my own note of appreciation, along with those coming in from many others, to Mike for his decade-plus sustained energy and leadership, and I wish him all the best in his retirement from NASA.[7]

Also, on June 20, 2018, **Scott Braun** [GSFC] became the Project Scientist (PS) for the GPM mission. Upon taking on this new role, Braun stepped down as the GOES Flight PS, a position he held since succeeding **Dennis Chesters** [GSFC, *emeritus*] in late 2017. Braun, who has been at GSFC since 1997, has previously served as a GOES Deputy PS, the TRMM PS, and was PI for the Hurricane and Severe Storm Sentinel (HS3) Earth Venture Suborbital investigation. He currently serves as PS for the upcoming TROPICS mission (an Earth Venture Instrument mission).

Braun replaces **Gail Skofronick–Jackson** [NASA HQ] who became the ESD Atmospheric Dynamics Program Manager and serves as Program Scientist for GPM, Aqua, and CYGNSS.[8] She served as GPM Deputy PS starting in 2006 and as GPM PS from 2014–2018. Following Braun's transition, **Joel McCorkel** [GSFC] was named the GOES Flight PS. McCorkel, the Deputy PS for the GOES Flight Project since 2015, is an expert in imager calibration and the deputy instrument scientist for TIRS-2 on Landsat 9. We wish everyone well in their new positions.

Finally, NASA's DEVELOP National Program, part of the Applied Sciences Program, is celebrating its twentieth anniversary this year. What began with three student interns in 1998 has evolved into a national program engaging hundreds of participants and partners each year. Turn to page 11 of this issue to learn more about DEVELOP's history and its 2018 Earth Science Application Showcase held at NASA HQ on August 1, 2018. ■

[5] The Earth Venture class was established by the First (2007) Earth Science Decadal Survey as a means to produce lower-cost, PI-led, competed orbital and sub-orbital missions that are built, tested, and launched in short time intervals. It includes Earth Venture Instruments (EVI); Earth Venture Sub-orbital (EVS) and Earth Venture Missions (EVM). Details can be found at *https://essp.nasa.gov/projects*.

[6] To learn more about the EVS-3 selections, visit *https://www.nasa.gov/press-release/new-airborne-campaigns-to-explore-snow-storms-river-deltas-climate.*

[7] Learn more about Mike Freilich's tenure at *https://science.nasa.gov/news-articles/nasa-earth-science-director-announces-retirement*.

[8] Aerosols and Clouds, Convection and Precipitation are identified as two of five *foundational observations* in the second Earth Science Decadal Survey, to be implemented as cost-capped medium- and large-sized missions to be directed or competed at the discretion of NASA. To learn more, see *Thriving on a Changing Planet: A Decadal Strategy for Earth Observation from Space* at *https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth.*

Note: List of undefined acronyms from the *Editor's Corner* and the *Table of Contents* can be found on **page 55**.

ICESat-2: Measuring the Height of Ice from Space

EDITOR'S NOTE: This feature content is taken from the ICESat-2 pre-launch mission brochure (*https://eospso.gsfc.nasa.gov/sites/default/files/publications/ICESat-2_missionBrochure_508.pdf*). While the intent is to reprint it with its original content largely intact, it has been modified to match the style used in *The Earth Observer*, and to fit the layout space allocated for it.

ICESat-2 will take measurements across the globe and provide an incredibly precise height map of Earth's global ice, water, and land surfaces in unprecedented detail. Its focus will be on Earth's poles, including the Arctic region where temperatures are rising faster than at other latitudes.

ICESat-2: Measuring the Height of Ice from Space

Ice is being lost across the globe, especially in the polar regions. The continental ice sheets of Greenland and Antarctica are shedding ice to the ocean and raising sea level. Arctic sea ice is less than half its 1980s volume. Fundamentally changing the Arctic, this ice loss may also be affecting North American and global weather.

NASA launched the Ice, Cloud and land Elevation Satellite-2 (ICESat-2) on September 15, 2018, to measure changes in Earth's ice and improve forecasts of the global impacts. With its fast-firing laser, the satellite will collect information enabling scientists to calculate—to within fractions of an inch—how much the vast ice sheets of Antarctica and Greenland rise or fall each year.

ICESat-2 will take measurements across the globe and provide an incredibly precise height map of Earth's global ice, water, and land surfaces in unprecedented detail—see *ICESat-2 Science Objectives* below. Its focus will be on Earth's poles, including the Arctic region where temperatures are rising faster than at other latitudes.

Hundreds of billions of tons of land ice melt into the ocean annually, raising sea levels worldwide. In recent years, meltwater from the ice sheets on Greenland and Antarctica alone has raised global sea level by more than a millimeter a year, and the rate is increasing. Based on computer simulations and satellite data, global sea level could be anywhere from 0.66 to 6.6 ft (0.2 to 2.0 m) higher by 2100 than in the first decade of this century. ICESat-2 data will document the ongoing height change of ice sheets and will help researchers narrow that range of possibilities to forecast sea level rise with greater certainty, allowing communities to be better prepared.

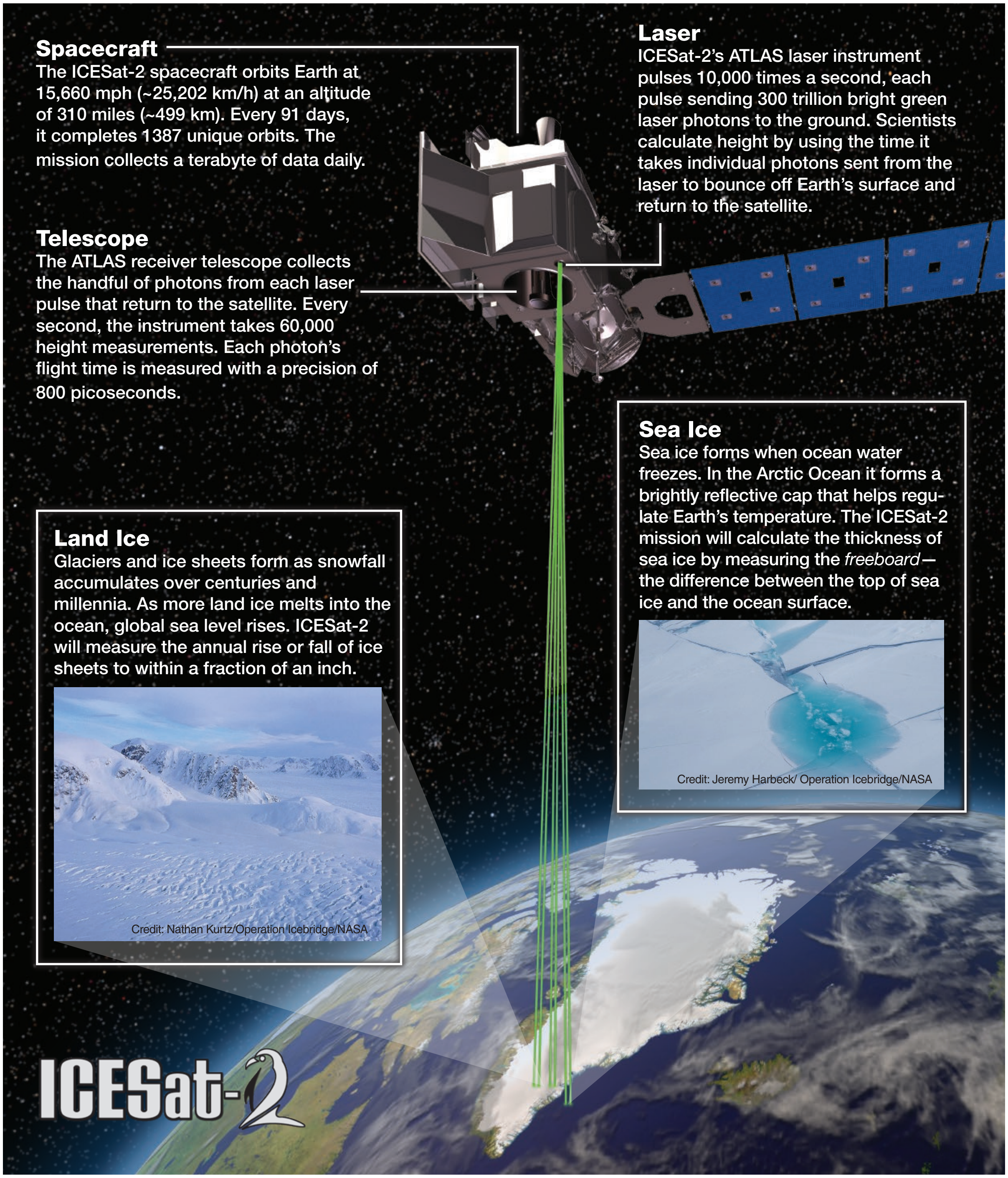
Floating sea ice doesn't change sea level when it melts, just like melting ice cubes don't overflow a glass of water. However, sea ice loss has a different suite of global consequences. The bright Arctic ice cap reflects the Sun's heat back into space. When white ice melts away, leaving dark waters, the ocean soaks up that heat. This alters wind and ocean circulation patterns that span the globe, affecting Earth's weather and climate. Shrinking sea ice cover also disrupts traditional ways of life for native Arctic communities, and changes habitats for wildlife such as polar bears and whales. While scientists routinely measure sea ice coverage from satellite images, they lack region-wide sea ice height measurements that would allow them to derive thickness and volume—height measurements that ICESat-2 will provide.

ICESat-2 Science Objectives

The ICESat-2 mission is designed to accomplish four science objectives:

1. Quantify how much melting ice sheets in Greenland and Antarctica contribute to sea level changes.
2. Quantify how ice sheets and glaciers are gaining or losing mass at a regional level, to help researchers understand the mechanisms behind those changes.
3. Estimate the thickness of sea ice and monitor any changes.
4. Measure the height of vegetation in forests and other ecosystems worldwide.

NASA's new Earth-observing satellite will measure the height of our planet's ice in unprecedented detail.



Each second, ICESat-2's only instrument—a laser altimeter—will fire 10,000 times, sending hundreds of trillions of photons to the ground in six beams of green light—see **Table 1** on page 6. The instrument, called the Advanced Topographic Laser Altimeter System (ATLAS), measures height by timing how long it takes individual photons to travel from the spacecraft to Earth and back—and does so with a precision better than a billionth of a second. In the course of three months, ATLAS will cover the globe with 1387 individual orbits, collecting billions of measurements to create a three-dimensional portrait of our planet.

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As the satellite orbits, it will also measure the height of the ocean and land beyond the polar regions. Researchers will be able to use the satellite's terabytes of data to study the planet's temperate and tropical latitudes. ATLAS is designed to measure both the tops of trees (*canopy height*) and the forest floor below, which—combined with existing datasets on forest extent—will help researchers estimate the amount of global vegetation.

Table 1. ICESat-2 Characteristics

Laser wavelength	532 nanometers
Transmitted pulse width	1.5 nanoseconds
Pulse repetition rate	10 kilohertz
Number of beams	6 beams, organized in 3 pairs
Beam spacing (across track)	295 ft (90 m) within pairs, 2.1 mi (3.2 km) separating the pairs
Illuminated spot diameter	56 ft (17 m)
Telescope aperture diameter	2.6 ft (0.8 m)
Single photon time-of-flight precision	800 picoseconds

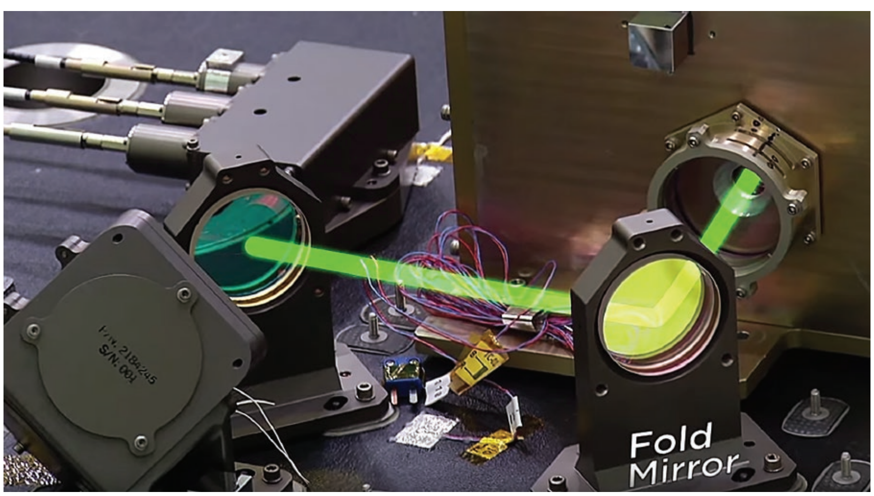


Figure 1. ICESat-2's laser beam has to make several turns as it travels through ATLAS, as seen in this illustrated image. Shown here, the pulses of light travel through a series of lenses and mirrors before beaming to the ground. This pathway along the optical bench serves to start the stopwatch on the timing mechanism, check the laser's wavelength, set the size of the ground footprint, ensure that the laser and the telescope are perfectly aligned, and split the laser into six beams, divided into three pairs. **Image credit:** NASA

Even prior to launch, potential data-users have been working with the ICESat-2 mission team to connect the mission science to societal needs. ICESat-2 measurements of reservoir heights could help local governments plan for flooding or drought, for example. Forest height maps, showing tree density and structure, could improve computer models that firefighters use to forecast wildfire behavior. Sea ice measurements could be integrated into forecasts the U.S. Navy issues for navigation and sea ice conditions.

NASA's ICESat-2 mission will extend a continuous data record on the height of Earth's ice. This record, started in 2003 with the original ICESat mission (which ended in 2010), has continued since 2009 with NASA's Operation IceBridge. IceBridge fills the data gap between ICESat and ICESat-2, with airplanes flying a suite of scientific instruments over the Arctic and Antarctic. The airborne campaign has provided essential information to improve sea ice forecasts and has charted the decline of several Antarctic glaciers and ice shelves, among many other accomplishments. With ICESat-2's advanced laser technology, NASA will provide even more detailed, more precise, and denser datasets on land and sea ice. The full potential of ICESat-2's data is unknown; the mission's profile of Earth measurements will open the door for discoveries not yet imagined.

Instrument Overview: The Advanced Topographic Laser Altimeter System (ATLAS)

To precisely time how long it takes a pulse of laser light to travel from the satellite to Earth and back, you need a really good stopwatch—one that can measure within a fraction of a billionth of a second. Nothing available met ICESat-2's exacting requirements, so the team behind ATLAS built one themselves. It and other ATLAS components make it one of the most advanced space lasers ever flown.

ATLAS has three major tasks: send pulses of laser light to the ground (while precisely determining where the laser is pointing), collect the returning photons in a telescope, and record the photon travel time. To do this, ATLAS will release 10,000 laser pulses a second. The light from the lasers, built by Fibertek, is at 532 nm—a bright green in the visible spectrum. As a pulse is fired, ATLAS splits the single laser beam into six—see **Figure 1**. The multiple beams from ATLAS are designed to

Icy Facts

Global land-ocean temperature index for 2017 relative to the 1951-1980 average: ↑ +0.9°C	Greenland ice mass change since 2002: ↓ -286 gigatons/year	Greenland ice loss 2002-2018: ↓ 4576 gigatons	Antarctic ice mass change since 2002: ↓ -127 gigatons/year

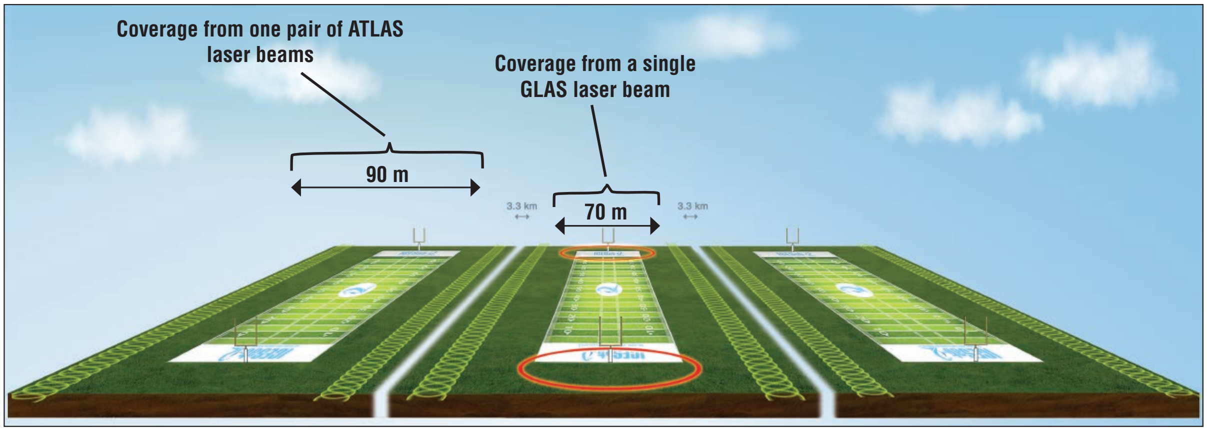


Figure 2. The high-frequency laser on ATLAS allows for nearly continuous coverage along the satellite ground track. If it flew over a football field, the GLAS instrument on the first ICESat would have taken a measurement in each end zone (two large circles). By comparison, ATLAS will take measurements within each yard line (series of small circles). ATLAS also creates a tighter footprint than GLAS did, providing more certainty of where on Earth's surface the photons are being reflected from. And while GLAS had one laser beam, ATLAS will have three pairs of beams—or six beams total—which means at the same time two laser beams are collecting data on one field, the other two pairs of beams can gather data on two parallel football fields 2.1 mi (3.3 km) apart. **Image credit:** NASA

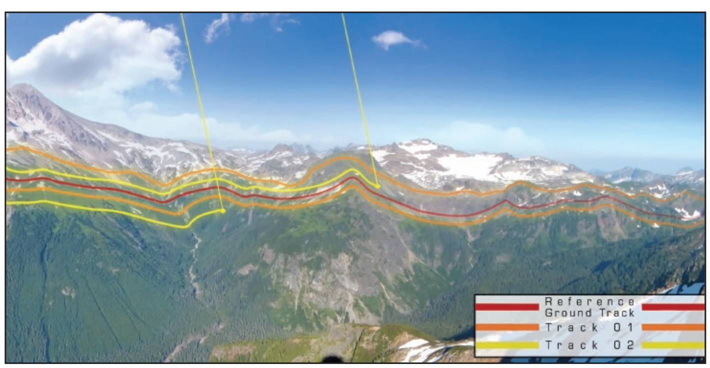
cover more ground than the first ICESat's Geoscience Laser Altimeter System (GLAS) instrument, which used only a single beam. The six beams are arranged in three pairs, designed to allow scientists to gauge the slope, or gradient, of the terrain in one pass—see *Slope Versus Elevation Change* below. With its incredibly fast pulse rate, ATLAS can take measurements every ~2.3 ft (70 cm) along the satellite's ground path. The footprint of each pulse is ~56 ft (17 m) in diameter. In comparison, GLAS took measurements roughly every 560 ft (170 m)—see **Figure 2**.

With its incredibly fast pulse rate, ATLAS can take measurements every ~2.3 ft (70 cm) along the satellite's ground path.

Slope Versus Elevation Change

Scientists analyzing data from the original ICESat mission were faced with a problem. As the satellite made multiple passes over an area, it was difficult to tell whether the ice had melted over time, or if the laser beam was simply pointed a bit off the path and down a hill. To be sure, they had to gather data on a particular site several times to first estimate the slope and then estimate ice loss.

ICESat-2 can determine the slope across the laser's path on a single pass. The updated satellite uses pairs of beams that straddle the reference ground track. Then, on subsequent passes, even if the two beams end up slightly upslope or downslope from where they were on the first pass, scientists can use the ground track to calculate elevation change.



This image depicts how one pair of laser beams will track on Earth as ICESat-2 passes overhead. The red line denotes the reference ground track, while the two orange lines represent ICESat-2's first pass and the two yellow lines represent beams from a later pass. Each time ATLAS collects data along a particular track, onboard software aims the laser beams so that the reference ground track is always between the two beams, as shown in the image. This allows scientists to combine the elevation and slope information from two different passes to determine elevation change along the same reference ground track.

About 300 trillion photons leave ATLAS with each pulse; only about a dozen from each beam are detected upon returning to the satellite's beryllium telescope. To ensure that the telescope is aligned to catch those returning photons, ATLAS engineers have designed and built a Laser Reference System. This system picks up a fraction of the laser light before it leaves the satellite to check the aim. If it's not aligned, ATLAS can steer the laser to correct it.

The photons that return to the ATLAS telescope are focused on six fiber optic cables that correspond to where the six laser beams will return. From those fibers, the photons pass through a series of filters, which only let through light that is at precisely 532 nm. When an individual photon makes it through the filters, it triggers a detector and its flight time is recorded. ATLAS can measure the time of flight of a photon to within 800 picoseconds (0.0000000008 seconds).

The time-tagged data for each returned photon is communicated to the electronics and communication system on the ICESat-2 spacecraft, before the data are sent to a ground station. Algorithms can use that travel time, laser pointing direction, and precise satellite position to determine the distance the photon traveled and—as a result—the height of the surface. However, one data point isn't sufficient to determine elevation with the required precision; hundreds of data points, averaged over different temporal and spatial intervals, are needed.

The number of data points collected over a given area will determine how precise the elevation measurements will be for a particular area. With more data points collected, the data-analyzing software more precisely measures the surface height. For example, over large areas such as the Greenland and Antarctic ice sheets, ICESat-2 will gather enough data points to estimate the annual elevation change within 0.16 in (4 mm).

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Over smaller areas, such as glaciers, the elevation estimates are less precise, because there are fewer data points. While detecting a dozen or so returning photons for each laser pulse, ATLAS will also detect a significant number of background photons. These photons did not originate from ATLAS, but from reflected sunlight from Earth's surface. Some may have exactly the same wavelength as the laser and thereby are allowed to pass through the filters. To isolate the laser photons from reflected photons, scientists will create photon cloud graphs showing thousands of data points—see **Figure 3** on page 9. By applying additional algorithms, which identify stronger signals within the photon cloud graphs, scientists can determine the elevation of Earth's ice, land, water, and vegetation.

Spacecraft Design and Launch

ICESat-2's single instrument, ATLAS, is the first of its kind flown in space—but the spacecraft that controls it and the rocket that launches it are tried-and-true machines. The spacecraft, which was built by Northrop Grumman, has a pedigree that includes the Landsat 4, 5, and 8 satellites; the planetary explorer Dawn spacecraft; and the Fermi Gamma-Ray Observatory. The assembled and tested ICESat-2 satellite launched from Vandenberg Air Force Base in California, aboard United Launch Alliance's Delta II rocket. It was the last Delta II rocket, which has launched more than 50 NASA science missions.

Northrop Grumman's LEOStar-3 spacecraft bus provides power and orbit control for ATLAS, as well as propulsion, navigation, attitude control, thermal control, data storage and handling, and ground communication. Four solar panels deployed after the launch to power the craft and the instrument, producing an average of 3800 W.

Icy Facts

Arctic sea ice extent has consistently shrunk below the 1980–2010 average since 2011.	**Between 2003 and 2009, Arctic sea ice declined in thickness by more than 23.6 in (60 cm).**

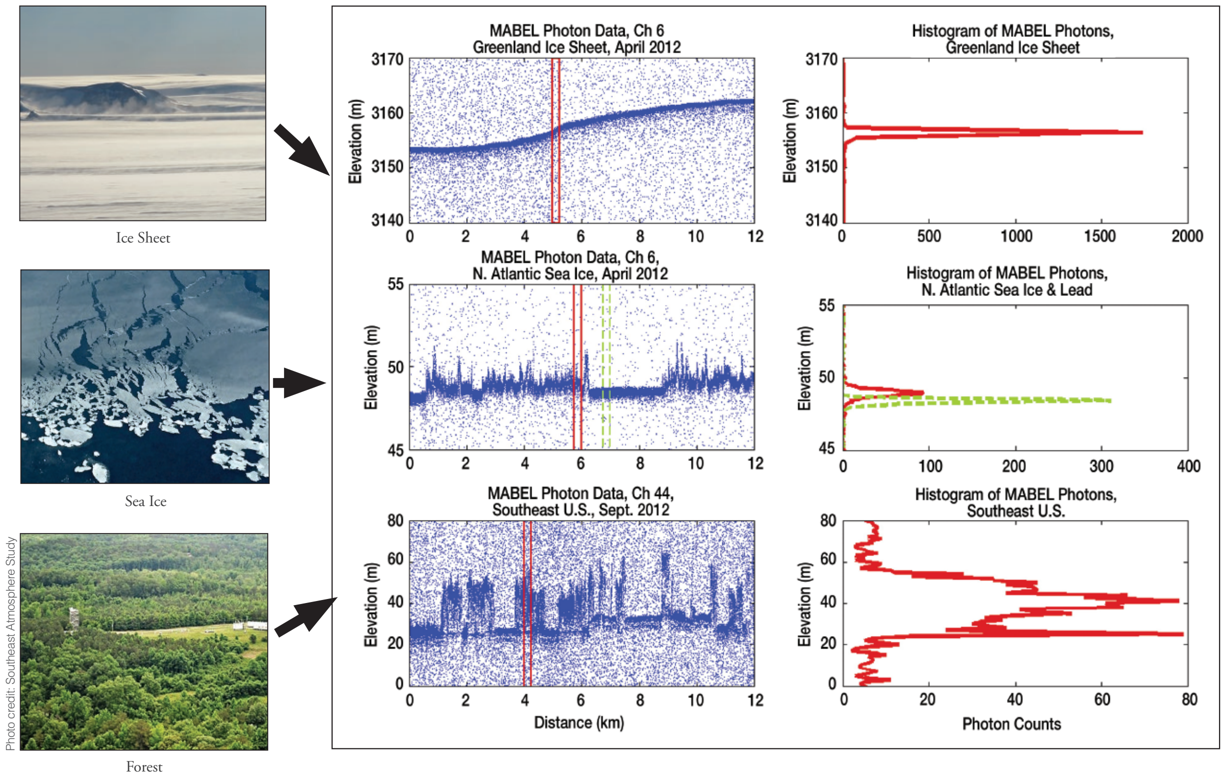

Figure 3. Scientists will analyze ICESat-2's data by plotting each photon that the satellite detects. Typical examples of these data plots, called *photon clouds*, are seen here for ice sheets [*top*], sea ice [*middle*], and vegetated areas [*bottom*]. For photon clouds over ice sheets, the surface can clearly be seen by the dense accumulation of photons. The "random" photons from all over the plot are indeed random and sporadic—these are photons from the Sun that naturally bounce off Earth and make it to ICESat-2's telescope and past the filters. On the graphic's right-hand side are plots of the photon density (histograms) for the photons between the two lines in the corresponding photon cloud. Over sea ice, researchers will calculate the height of the ice itself (two solid lines) as well as for the adjacent open water (two dashed lines), in order to calculate the portion of the sea ice that is above sea level. The photon cloud is more diffuse when measuring vegetation, but from the histogram researchers can detect the crown of the tree as well as the ground surface, which is the narrow peak below the tree. **Image credit:** NASA

The spacecraft has an onboard data recorder that will store more than the 580 Gb of data per day that's collected by the instrument and sent back to Earth. An X-band downlink system can transmit 220 Mbps.

The launch of ICESat-2 is followed by a 60-day check-out period, where the spacecraft and instrument are tested to ensure everything is functioning as it should.

Where in Space Is ICESat-2?

ICESat-2's spacecraft and its ground-based computer programs are designed with strict specifications so scientists can know precisely where on the planet's surface the instrument is taking measurements.

It is also critical to know where in space the satellite is positioned. To achieve this, onboard the spacecraft is a global positioning system (GPS), a star tracker, and very accurate knowledge of the satellite's center of gravity. Scientists will conduct ground calibration studies and analysis to refine the positioning even further. Knowing the spacecraft's altitude is key, since the instrument measures the distance from itself to the ground; if the laser and receiver are higher or lower than expected, the elevation measurements will be off.

ICESat-2's spacecraft and its ground-based computer programs are designed with strict specifications so scientists can know precisely where on the planet's surface the instrument is taking measurements.

Since 1870, sea level has risen about 8 in (20 cm).

ICESat-2 will collect data within a swath width of 56 ft (17 m).

Ground System and Data Products

The spacecraft and instrument, together called the observatory, are controlled from the Mission Operations Center at Grumman Corporation in Dulles, VA. The Mission Operations Center will send software commands to ICESat-2 through the ground stations in Svalbard, Norway, and Poker Flat, AK.

The ATLAS instrument is monitored by the Instrument Support Facility at NASA's Goddard Space Flight Center (GSFC). ICESat-2 will transmit its science data to a ground station in Svalbard, Norway, Poker Flat, AK, or Wallops Island, VA. The raw data are sent to GSFC where the data products are generated. A terabyte a day of these products is sent to the National Snow and Ice Data Center (NSIDC) in Boulder, CO. The NSIDC will distribute data products to the public free of charge. For a list of data products, visit *https://icesat-2.gsfc.nasa.gov/science/data-products*.

Data will be available for download from *http://nsidc.org*.

ICESat-2 will provide a wealth of detailed sea ice thickness data. The satellite's instrument will measure freeboard—the distance between the top of the ice and the ocean surface. From that, algorithms can be used to determine the ratio of ice above water to ice below water to calculate the thickness of the floating ice.

Conclusion

NASA and other organizations have been monitoring sea ice extent from polar-orbiting satellites for more than four decades, beginning with the Nimbus-7 satellite in the late 1970s.[1] Scientists have charted the annual variations in sea ice and documented the decline in the ice's extent in recent years. Since 2011, Arctic sea ice extent has consistently shrunk below the 1980–2010 average. The first ICESat mission, in operation from 2003 to 2010, demonstrated that between those years Arctic sea ice thickness declined overall by more than 2 ft (60 cm). ICESat-2 will provide a wealth of detailed sea ice thickness data. The satellite's instrument will measure *freeboard*—the distance between the top of the ice and the ocean surface. From that, algorithms can be used to determine the ratio of ice above water to ice below water to calculate the thickness of the floating ice.

On land, satellite data show that ice sheets have not been in balance this century, i.e., the amount of snowfall and the amounts of ice lost through calving and melt are not equal. ICESat demonstrated that the margins of ice sheets were dropping in height, in some places by 3.3 ft (1 m) or more a year. Globally, sea level has risen about 8 in (20 cm) since the beginning of the twentieth century and more than 2 in (5 cm) in the last 20 years alone. A 2017 study suggested that sea level rise is accelerating and projected that by 2100 sea level will rise 26 in (65 cm).

ICESat-2 will be able to detect centimeter-level rises or falls in the height of the ice sheets, which will give researchers more data on the precise location, and amount, of ice loss on our planet. The sheer number of data points ICESat-2 will collect, together with the laser's small footprint size means that researchers will have exciting and useful information on the changes in ice height on the scale of individual glaciers—in Greenland and Antarctica, as well as other parts of the globe. This, in turn, will allow scientists to better understand the current situation and better predict how much sea level will rise and the impacts to coastal communities globally.

To learn more about ICESat-2, visit *https://icesat-2.gsfc.nasa.gov*. ■

[1] To learn more about Nimbus 7, see "Nimbus Celebrates 50 Years" in the March–April 2015 issue of *The Earth Observer* [**Volume 27**, **Issue 5**, pp. 18-31—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Mar_Apr_2015_color_508.pdf#page=18*].

NASA's DEVELOP Program Recognizes 20 Years of Science Serving Society

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Introduction

The NASA DEVELOP National Program bridges the gap between science and society by demonstrating how NASA Earth Science data can be applied to environmental decision making. As part of the Earth Science Division's Applied Sciences' Capacity Building Program, DEVELOP empowers individuals and institutions to access and apply Earth-observation data through feasibility studies focused on localized environmental issues.

The DEVELOP approach to capacity building is dual in nature. Not only do individual project participants gain skill in using Earth observations themselves, but the participating partner organizations increase their institutional knowledge of these skills as well. DEVELOP participants (e.g., college students, recent graduates, transitioning career professionals, and active-duty military service members) work on 10-week projects under the guidance of science advisors, rapidly building their technical knowledge of NASA Earth Science concepts, Earth-observation datasets, general remote sensing techniques, and geographic information systems (GIS). Skill development is fostered throughout the process with a focus on technical writing, data visualization, and best science communication practices, along with effectively contributing to a team, and—as a result—interdisciplinary awareness and networking.

The DEVELOP approach to capacity building is dual in nature. Not only do individual project participants gain skill in using Earth observations themselves, but the participating partner organizations increase their institutional knowledge of these skills as well.

DEVELOP project partners (e.g. local, state, and federal government agencies, nonprofits, private sector, and academia) are central to the creation of a project, which begins with a needs assessment focused on the environmental concern at hand and the partner's related decision-making process. The DEVELOP team guides the partner throughout the project by introducing them to new NASA datasets and methodologies and shares the case study results at the end of the 10 weeks during a "partner handoff" event. This immersive, hands-on approach to applications provides experiential learning that builds on participants' educational experiences and utilizes and improves interdisciplinary skills that contribute to effective decision making.

Program History

The program's roots stem from the summer of 1998 when three summer interns at NASA's Langley Research Center (LaRC) worked with **Michael Ruiz** [LaRC—*DEVELOP Program Manager*] to author a white paper titled *The Practical Applications of Remote Sensing.* Concurrently, the Digital Earth Initiative, a federal interagency project dedicated to furthering humans' understanding of the planet, initiated an effort to increase public access to federal information about the Earth and the environment. These two ventures set the stage for the creation of a new student internship program within NASA. As a result, the DEVELOP program was officially formed. Early successes arose from the alignment of real-world projects focused on issues faced by local and regional communities. The program grew beyond LaRC into a national program with regional offices located in places such as Wise, VA; Mobile, AL; Fort Collins, CO; Athens, GA; Asheville, NC; Pocatello, ID; Tempe, AZ; and Boston, MA, as well as several located at other NASA field centers (Ames Research Center,

Figure 1. Map of DEVELOP locations in the summer of 2018. **Image credit**: NASA DEVELOP National Program

Goddard Space Flight Center (GSFC), Jet Propulsion Laboratory, and Marshall Space Flight Center)—see **Figure 1**.

In 2012, DEVELOP expanded its participant eligibility from solely matriculated students to include recent graduates, transitioning career professionals, and active-duty military service members, who today collectively make up over half of the participant population. That same year, DEVELOP established its Fellow Class, which provides one-year-long opportunities to recent graduates to support the program on a national scale with a variety of responsibilities—e.g., project coordination, geoinformatics, communications, impact analysis, and information technology.

Over the course of the past 20 years, the program has received three NASA Group Achievement Awards, won data visualization competitions and conference presentation contests, and published results from project work in 18 peer-reviewed journal articles.

Programmatic Highlights

From 1998 to the current 2018 fall term, DEVELOP has engaged 4,671 participants who have conducted 931 projects. These projects have demonstrated the applications of NASA Earth observations to a wide variety of sectors, addressing topics such as drought monitoring, vector-borne disease risk, water-quality assessments, pre- and post-wildfire mapping, agriculture monitoring, and critical habitat identification. Collectively, these projects have had an impact on all 50 U.S. states and have even had global reach, with projects focused on needs in over 65 countries. Over the course of the past 20 years, the program has received two NASA Group Achievement Awards and a Silver Achievement Medal, won data visualization competitions and conference presentation contests, and published results from project work in 18 peer-reviewed journal articles. DEVELOP has also been recognized by policy makers in several states, such as the 2002 Virginia House of Representatives' Joint Resolution No. 442, which commended DEVELOP and its activities throughout the Commonwealth, and in 2013, when the Mobile, AL, city council and mayor proclaimed November 26 as "DEVELOP Day" in the city in recognition of the tenth anniversary of DEVELOP's office in Mobile.

Twentieth Anniversary Activities

In recognition of the twentieth anniversary and the many accomplishments of the program, DEVELOP pursued several activities throughout 2018 to reconnect with alumni and past project partners, engage with the applied-science community, and highlight the broad impacts of the program. Led by DEVELOP's 2018 Fellow Class, the anniversary recognition included activities such as:

- Creating an anniversary logo and webpage hosted on the DEVELOP website, chronicling DEVELOP's history with an overview and event timeline;

- producing an anniversary promotional video and a Virtual Poster Session "All-Stars" competition that highlighted project videos from the past five years;
- constructing a "DEVELOPing America" layer for the program's interactive mapper, which highlights 50 different projects, each impacting a different U.S. state;
- hosting "DEVELOP Day" events at each of its 13 locations that brought together partners, advisors, alumni, current participants, and other stakeholders to recognize the contributions of each DEVELOP location;
- designing anniversary-themed presentation templates, a retro-styled poster series that highlights each office, and a project highlight booklet that features one project from each location; and
- engaging current and past participants through a brown-bag speaker series that featured alumni discussing career paths, a series of mapping and trivia competitions between locations, and multiple volunteer "mapathons."

For more information about the DEVELOP Anniversary activities, visit *https://develop.larc.nasa.gov/20thanniversary.php.*

2018 Annual Earth Science Applications Showcase

Since 2013, DEVELOP has hosted an Annual Earth Science Applications Showcase at NASA Headquarters at the end of each DEVELOP summer term. The event features the Applied Sciences Program's many contributions to society through the application of Earth observations and includes highlight presentations, *flash talks* (rapid, 4-minute presentations consisting of 12 slides that automatically advance every 20 seconds), and speaker panels. This year's showcase took place on August 1, 2018, and included a highlight presentation, 12 flash talks, a panel of partners and DEVELOP alumni discussing the benefits of Earth observations and Applied Sciences' activities, and a special DEVELOP anniversary presentation that included the distribution of multiple awards.

Since 2013 DEVELOP has hosted an Annual Earth Science Applications Showcase at NASA Headquarters at the end of each DEVELOP summer term.

Thomas Zurbuchen [NASA Headquarters (HQ)—*Associate Administrator of the Science Mission Directorate (SMD)*] and **Michael Freilich** [NASA HQ—*Director of the Earth Science Division*] opened the event with a welcome at the start of the highlight presentation, sharing sentiments regarding the value of the Applied Sciences Program, the substantial results of its projects, and the importance of the work for societal benefit.

Lawrence Friedl [NASA HQ—*Director of the Applied Sciences Program*] and **Nancy Searby** [NASA HQ—*Capacity Building Program Manager*] gave an overview of the Applied Sciences Program and its Capacity Building activities, which led to brief presentations that focused on five (of the eight) thematic application areas of the Applied Sciences Program.[1] The topics and the presenters included:

1. *Ecological Forecasting*: **Woody Turner** [NASA HQ—*Ecological Forecasting Program Manager*] and **Africa Flores** [University of Alabama in Huntsville].
2. *Disasters*: **David Green** [NASA HQ—*Disasters Program Manager*] and **Elizabeth Hook** [Science Systems and Applications, Inc. (SSAI)].
3. *Health & Air Quality*: **John Haynes** [NASA HQ—*Health & Air Quality Program Manager*] and **Meg Fredericks** [SSAI].
4. *Water Resources*: **Brad Doorn** [NASA HQ—*Water Resources Program Manager and Agriculture & Food Security Program Manager*], **Sydney Neugebauer** [SSAI], and **Neil Ganju** [U.S. Geological Survey].

[1] The application areas not represented were: Energy, Urban Development, and Transportation & Infrastructure.

5. *Agriculture & Food Security*: **Brad Doorn** [NASA HQ—*Water Resources and Agriculture & Food Security Program Manager*], **Jeremy Rapp** [SSAI], and project partner **Kelly Kulhanek** [University of Maryland, vanEngelsdorp Honey Bee Research Laboratory].

Thomas Zurbuchen [NASA HQ—*Associate Administrator for SMD*] gives welcoming remarks to start the Annual Earth Science Applications Showcase highlight presentation. **Photo credit:** Joel Kowsky [NASA]

DEVELOP Project Highlights

The showcase highlighted three of DEVELOP's summer projects from different DEVELOP offices. Each project focused their research within a different thematic area and worked with stakeholders to demonstrate how NASA Earth-observation data could address the needs. These partners were interested in the capabilities of NASA's Earth Observations to address urban heat vulnerability in Richmond, VA, investigate sea level rise resiliency in marshes in Massachusetts, and evaluate honey bee health indicators in New England.

Richmond Health & Air Quality (DEVELOP Office Virginia—Langley)

Team members: **Meg Fredericks**, *Project Lead*, **Patricia Abdurigimova**, **Simeon Brown**, and **Joshua Turner.** *Advisor:* **Kenton Ross** [LaRC—DEVELOP *National Science Advisor*].

"What the urban heat island study is doing for us, is making it very clear how urgent it is to acknowledge why green infrastructure is important to cool neighborhoods down and create a healthier city."

*—**Giles Harnsberger** [Groundwork RVA—Executive Director]*

The Richmond Health & Air Quality project partnered with Groundwork RVA (a nonprofit organization in Richmond, VA) and the Science Museum of Virginia to apply data from the Landsat 5 Thematic Mapper (TM), Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS), and Terra Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) to map the temporal and geographic distribution of urban heat in Richmond, VA. Investigating data from the past two decades, the team found uneven spatial distribution of land-cover types, meaning that some neighborhoods are more negatively impacted by the urban heat island effect than others. Utilizing NASA Earth observation data, the team identified areas of impervious surfaces and tree cover, which were combined with U.S. Census data related to age, health, socioeconomic status, and minority status—see **Figure 2**. Integrating satellite data with socioeconomic data, the team produced a heat vulnerability assessment that provided the project partners with greater spatial understanding of the most vulnerable populations. Groundwork RVA will use the conclusions drawn from land surface temperature and land surface time-series maps along with the vulnerability index, to influence local policy and establish small-scale interventions, such as planting trees in the most negatively impacted neighborhoods.

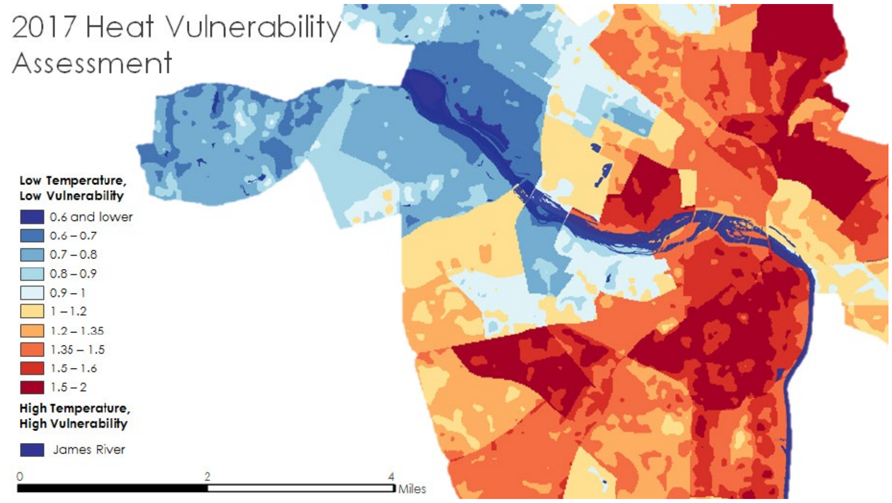

Figure 2: This comprehensive heat vulnerability assessment map of Richmond, VA, was created by combining a heat vulnerability index with land surface temperature data from Landsat 5 TM and Landsat 8 OLI/TIRS. The map highlights the areas of the city where high land surface temperatures and vulnerability to extreme heat coincide. **Image credit**: NASA DEVELOP National Program

Plum Island Estuary Water Resources (DEVELOP Office Massachusetts—Boston)

Team members: **Henrik Westerkam**, *Project Lead*, **Ruizhe Guo**, **Sydney Neugebauer**, and **Linnea Smith.** *Advisor*: **Cedric Fichot** [Boston University].

Salt marshes are critical for resilience in coastal communities, providing protection against storm surge and floods, controlling erosion, and playing a role in carbon sequestration. To evaluate the vulnerability of Massachusetts's Plum Island Estuary to sea level rise, the Plum Island Estuary Water Resources project used Landsat 8 and Copernicus Sentinel-2[2] satellite imagery to quantify sediment supply throughout the marsh. The team generated a localized algorithm that derives suspended sediment concentration from remote sensing reflectance. Satellite-derived suspended sediment concentration provides greater geographic coverage and allows for more-frequent observations than traditional *in situ* data collection methods. This enables project partners, the U.S. Geological Survey Woods Hole Coastal and Marine Science Center, U.S. Fish and Wildlife Service's Parker River National Wildlife Refuge, and the Long Term Ecological Research Network, to effectively allocate management resources. Suspended sediment concentration and flux maps will help inform management decisions and provide researchers at the various partner organizations with high-resolution information regarding the resilience of the Plum Island Estuary to sea level rise—see **Figure 3**.

Figure 3: This image shows suspended sediment concentration in Massachusetts's Plum Island Estuary, derived from Landsat 8 OLI data obtained on February 6, 2017, which provides an evaluation of marsh vulnerability to sea level rise. **Image credit**: NASA DEVELOP National Program

[2] Each Sentinel mission is based on a constellation of two satellites to fulfil revisit and coverage requirements, providing robust datasets for Copernicus Services. Sentinel-2 is a land imaging mission similar in scope to U.S. Geological Survey–NASA Landsat missions. Learn more about the Sentinel missions at *http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview4*.

New England Agriculture & Food Security (DEVELOP Office Maryland—Goddard)

Team members: **Jeremy Rapp**, *Project Lead*, **Victor Lenske**, **Eyob Solomon**, and **Ryan Young.** *Advisor*: **John Bolten** [GSFC].

The New England Agriculture & Food Security team partnered with the Urban Beekeeping Laboratory and Bee Sanctuary, Inc., University of Maryland vanEngelsdorp Honey Bee Research Laboratory, The Bee Informed Partnership Inc., and the BeekeepingIO app (*https://app.beekeeping.io*) to create an assessment tool to identify correlations between Earth-observation data and local beehive health. This work supports the improved understanding of relationships between environmental, seasonal, and regional changes—and ultimately honey bee hive success. The honey bee (*Apis mellifera*) plays a crucial role in the pollination of agricultural food crops, including more than 70 fruits and vegetables that make up American diets, and more than one-third of global food crops. The assessment tool, named Honeybee Informatics Via Earth Observations (HIVE-OS), was created in Google Earth Engine and incorporates *in situ* data collected from local hives and apiaries; biophysical variables, such as vegetation indices; and soil-moisture satellite data. The tool utilizes a suite of NASA Earth observations including imagery from Landsat 7 and 8, as well as Sentinel-2, Soil Moisture Active Passive (SMAP), Shuttle Radar Topography Mission (SRTM), and the Global Precipitation Measurement (GPM) Integrated Multi-satellitE Retrievals for GPM (IMERG) precipitation products. The team leveraged citizen science data, NASA Earth observations, and nationally reported statistics to develop a comprehensive methodology that they used to illuminate environmental variables that are linked to honey bee prosperity in the New England region of the U.S. from 2016 to 2018. The HIVE-OS tool will aid in developing historical trends in honey bee welfare and will provide insight for better understanding of bee habitat suitability conditions—see **Figure 4**.

"This large-scale satellite data that NASA DEVELOP is helping us use is really going to enable us to make large scale correlations about the factors we're seeing in honey bees and the physical interactions that they're having with their landscapes."

-Kelly Kulhanek *[University of Maryland, vanEngelsdorp Honey Bee Research Laboratory—Researcher]*

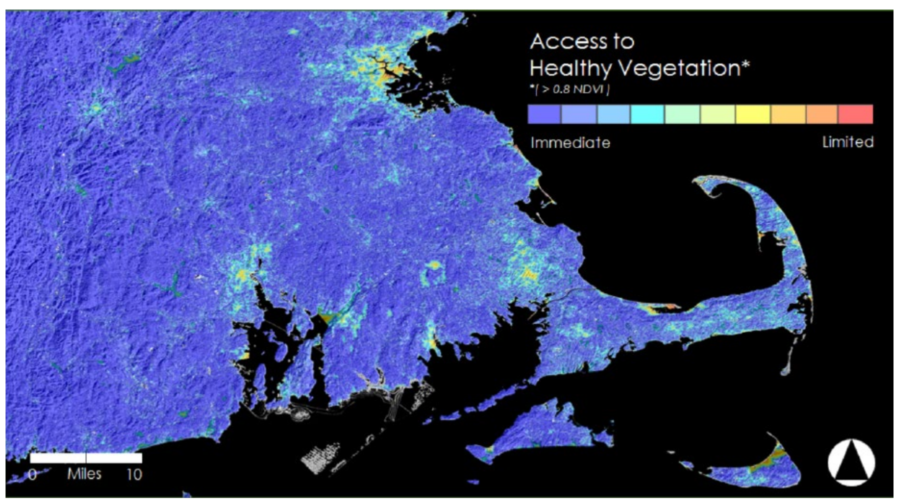

Figure 4: Landsat 8 OLI imagery from 2017 of southeastern Massachusetts highlighting areas where honey bee access to high-productivity vegetation is limited. **Image credit**: NASA DEVELOP National Program

End User and Alumni Panel: Perspectives on the Practical Benefits of NASA Earth Observations & The Applied Sciences Program

Panelists: *Current Project Partners:* **Hilary Brumberg** [Osa Conservation], **Neil Ganju** [U.S. Geological Survey], **Kelly Kulhanek** [University of Maryland vanEngelsdorp Bee Research Laboratory], and **Lina Katerine Vergara** [Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM), Colombia].

Alumni: **Sean McCartney** [SSAI], **Steve Padgett-Vazquez** [Project Consulting Services], **Ifeoma Melissa Collins** [World Resources Institute], and **Lauren Ely** [U.S. Census Bureau].

A panel of eight speakers was convened that featured four project partners and four DEVELOP alumni, speaking to the benefits of Earth observations, the impact of the Applied Sciences' Capacity Building Program activities on their organizations and careers, and contributions to the geospatial community. **Nancy Searby** served as moderator. The end-user panelists shared insights into how the increased awareness of NASA Earth Science and its applications—gained from partnering with the Applied Sciences Program—has helped their organizations. They also offered advice to other organizations interested in seeing how such data may benefit their own decision making. The alumni panelists discussed their experiences within the DEVELOP program, how they have influenced their career trajectories, and provided advice to current DEVELOP participants.

Anniversary Presentation and Awards Ceremony

The showcase concluded with a twentieth anniversary presentation sharing the history of DEVELOP and its current reach by the DEVELOP National Program Office, as well as the announcement of several awards. Science Systems and Applications, Inc. (SSAI) awarded three academic scholarships to outstanding DEVELOPers who are currently pursuing higher education: **Sydney Neugebauer** [DEVELOP Plum Island Estuary Water Resources Team Member]; **Conor Mulderrig** [DEVELOP South Dakota Ecological Forecasting Team Member]; and **Max Stewart** [DEVELOP Glen Canyon Ecological Forecasting Team Member]. In addition, DEVELOP named **Jillian LaRoe** [DEVELOP Grand Canyon Water Resources Team Member] and **Harrison Knapp** [DEVELOP Southern California Water Resources Team Member] as "DEVELOPers of the Term" for their valuable contributions to their projects and passion for the program.[3]

The summer Applications Showcase served to illustrate the reach of both DEVELOP and the greater Applied Sciences Program's activities, the innovative methodologies and breadth of projects and applications, and the many benefits of these activities to society.

The Fellows and Center Leads (DEVELOP one-year leadership positions) for the "Class of 2019" were also unveiled, and the day ended with **Michael Freilich** presenting **Michael Ruiz** NASA's Exceptional Service Medal for "…outstanding leadership, exemplary achievement, and significant contributions to NASA's Earth Science Division through sustained program performance and unparalleled drive to foster the leaders of tomorrow and apply Earth observations for societal benefit."

The DEVELOP summer 2018 national team and NASA officials at the Annual Earth Science Applications Showcase on August 1, 2018. **Photo credit:** Harlen Capen [LaRC]

Conclusion

The twentieth anniversary has provided an exciting opportunity to reflect on the past two decades of DEVELOP, appreciate the program's significant evolution, and begin to discern its extensive impact on program participants and partners. Contributions made to the geospatial workforce and to environmental decision making demonstrate the increasing value of DEVELOP's unique and nimble approach to capacity building. The summer Applications Showcase served to illustrate the reach of both DEVELOP and the greater Applied Sciences Program's activities, the innovative methodologies and breadth of projects and applications, and the many benefits of these activities to society. DEVELOP continues to pursue its mission to integrate NASA Earth observations into local community decision making and cultivate the future workforce by addressing current environmental issues.

For more information about the DEVELOP program, visit *https://develop.larc.nasa.gov/index.php*.

[3] All individuals listed in this paragraph are affiliated with SSAI.

For more information about the DEVELOP projects and to view the project videos, visit

- Richmond Health & Air Quality: *https://develop.larc.nasa.gov/2018/summer/RichmondHAQ.html*
- Plum Island Estuary Water Resources: *https://develop.larc.nasa.gov/2018/summer/PlumIslandWaterII.html*
- New England Agriculture & Food Security: *https://develop.larc.nasa.gov/2018/summer/NewEnglandAg.html.* ■

Congratulations to AGU and AMS Award Winners!

Several notable Earth scientists will receive awards from the American Geophysical Union (AGU) and American Meteorological Society (AMS) at their annual meetings in December 2018 and January 2019, respectively. *The Earth Observer* is pleased to recognize those from NASA centers, who include:

AGU

Section Awardees and Named Lecturers

Paul A. Newman [NASA's Goddard Space Flight Center (GSFC)] has been named the 2018 *Jule Gregory Charney Lecture*.

Ludovic Brucker [GSFC, Universities Space Research Association, Goddard Earth Sciences Technology and Research (GESTAR)] has been chosen to receive the 2018 *Cryosphere Early Career Award*.

Richard S. Gross [NASA/Jet Propulsion Laboratory (JPL)] has been chosen to receive the 2018 *Ivan I. Mueller Award for Distinguished Service and Leadership*.

To view the full list of Section Awardees and Named Lecturers, visit *https://eos.org/agu-news/2018-agu-section-awardees-and-named-lecturers*.

Fellows

Donald F. Argus [NASA/JPL, California Institute of Technology], **Dorothy K. Hall** [University of Maryland and Cryospheric Sciences Laboratory, GSFC], **Christa D. Peters-Lidard** [GSFC], **Gavin A. Schmidt** [NASA's Goddard Institute for Space Studies], and **Christopher R. Webster** [JPL, California Institute of Technology] have been named 2018 Fellows of the AGU. The AGU Fellows program recognizes members who have made exceptional contributions to Earth and space sciences as valued by their peers and vetted by section and focus group committees. This honor may be bestowed on only 0.1% of the membership in any given year.

To see the full list of AGU Fellows, visit *https://eos.org/agu-news/2018-class-of-agu-fellows-announced*.

AMS

Award Winner

Patrick Minnis [NASA's Langley Research Center] has been chosen to receive the AMS's 2019 *Verner E. Suomi Technology Medal* for numerous, innovative advances in remote sensing techniques to understand clouds and radiative processes.

To see the full list of AMS Award Winners, visit *https://www.ametsoc.org/index.cfm/ams/about-ams/ams-awards-honors/2019-awards-and-honors-recipients*.

Fellows

Scott A. Braun and **George J. Huffman** [both from GSFC] have been named 2019 Fellows of the AMS. To be elected a Fellow of the AMS is a special tribute for those who have made outstanding contributions to the atmospheric or related oceanic or hydrologic sciences or their applications during a substantial period. This designation is conferred upon not more than 0.2% of all AMS members in any given year.

To see the full list of AMS Fellows, visit *https://www.ametsoc.org/index.cfm/ams/about-ams/ams-awards-honors/2019-awards-and-honors-recipients*.

An Overview of USGS-NASA Landsat Science Team Activities During 2018

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Introduction

Two meetings of the U.S. Geological Survey (USGS)-NASA Landsat Science Team (LST) took place in 2018. The USGS Earth Resources Observation and Science (EROS) Center hosted the winter meeting, which took place February 21-22 in Sioux Falls, SD. The University of Colorado-Boulder hosted the summer meeting, which was held August 8-10 in Boulder, CO.

The objectives of the winter LST meeting were to introduce the new 2018-2023 LST members, review LST member roles and responsibilities, receive status updates on Landsat 7 and Landsat 8 mission operations, review Landsat 9 development progress, and establish science team priorities for the LST's five-year term.

The summer LST meeting objectives included review of Landsat's no-cost, nondiscriminatory-access data policy, status updates on Landsat data product evolution, future archive collection and reprocessing plans, Landsat calibration/validation (cal/val) activities, and identifying LST synergy with NASA's Multi-Source Land Imaging Program (MuSLI). Meeting participants also toured Ball Aerospace, located in Boulder, where Landsat 9's Operational Land Imager Two (OLI-2) is being built.

This article begins with a brief review of the Landsat mission to-date followed by a short synopsis of the USGS–NASA LST's makeup, role, impact, and contributions to the Landsat program. Next, the 2018-2023 USGS–NASA LST is introduced, and its key responsibilities to the Landsat program are described. The article finishes with summaries of both winter and summer LST meetings that took place during 2018. The USGS-NASA LST meetings are open and transparent and all meeting materials are publicly accessible at *https://landsat.usgs.gov/landsat-science-teams*.

Review of the Landsat Mission to Date

The Landsat mission began in July 1972 with the launch of Landsat 1 (1972-1978), formerly known as Earth Resources Technology Satellite (ERTS-A or ERTS-1), carrying Multispectral Scanner (MSS) and Return Beam Vidicon (RBV) sensors. The MSS system continued with Landsat 2 (1975-1978) and Landsat 3 (1978-1983), and provided visible-to-near-infrared (VNIR) multispectral coverage.

Beginning with the Landsat 4 mission (1982-1993), the MSS sensor was accompanied by an additional Thematic Mapper (TM) sensor as well as initiation of thermal infrared (TIR) measurements. The changes from Landsat 3 to 4 (in particular, moving from MSS to TM) with improved radiometry, additional spectral coverage [e.g., adding shortwave infrared (SWIR—sometimes called middle infrared) and TIR] as well as increases in spatial resolution, resulted in a significant advancement in Landsat sensor design and resultant information content. The shift from MSS, with 60-m (~197-ft) spatial resolution, to TM, with 30-m (~98-ft) spatial resolution, provided sufficient detail to enable human interactions with the Earth's surface to be characterized over large areas and monitored through time.

The 2018-2023 USGS-NASA Landsat Science Team. **Photo credit:** USGS EROS

Landsat 5 (1984-2011) also had a TM, which was nearly identical to the TM on Landsat 4 and which remained in a science-imaging orbit for a remarkable 28 years and 10 months. The TM sensor also provided additional SWIR multispectral coverage as well as one TIR spectral band.

The subsequent improvements to Landsat sensors described below have built upon the successful TM design, keeping key elements to enable continuity of measurements (e.g., orbital characteristics, 30-m spatial resolution) but leaving opportunity for improvement (e.g., adding additional spectral bands, improved radiometry). At this point, the next step in Landsat sensor development came with the Enhanced Thematic Mapper (ETM), which, as its name implies, was an enhanced version of TM that added a VNIR panchromatic spectral band, and low- and high-gain modes for the TIR spectral band.

Landsat 6 (launched in 1993) had an ETM onboard; unfortunately, the satellite failed to reach orbit. In 1999 Landsat 7 was launched, with the Enhanced Thematic Mapper Plus (ETM+) onboard. The Landsat 7 ETM+ has been in operation with stable on-orbit performance for ~20 years—well beyond its 5-year design life. Landsat 7 was the first system to carry full- and partial-aperture solar calibrators to monitor sensor health and performance. The Landsat 7 ETM+ sensor has multispectral VNIR, SWIR, and TIR coverage. In May 2003 Landsat 7 experienced a failure with the Scan Line Corrector (SLC), resulting in a status described as *SLC-off,* whereby there are systematic, zig-zag, data gaps along the image edges. Since initial discovery of the SLC-off failure and subsequent characterization of the malfunction as permanent, many approaches for mitigating the issue have been developed and documented.

Landsat 8 (2013-present), known as the Landsat Data Continuity Mission (LDCM) during development, was launched in February 2013 and carries two sensors, the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). Landsat 8 OLI has significantly improved radiometry over prior Landsat sensors. Ultrablue and infrared cirrus spectral bands were added to OLI to enhance coastal and fresh water remote sensing science, improve capabilities to compensate for atmospheric effects, and increased cloud detection accuracy. Landsat 8 TIRS measures emitted thermal radiance in two spectral regions to enable more accurate atmospheric characterization and compensation with the intent of improving the fidelity of surface temperature retrievals. The upcoming Landsat 9 will be nearly identical to Landsat 8 and will carry two sensors, the OLI-2 and TIRS-2.[1] The launch date for Landsat 9 is targeted for December 2020. Planning is now underway for a Landsat 9 follow-on.

[1] Landsat 9 will fly near-identical copies of the OLI and TIRS instruments that were flown on Landsat 8. The TIRS instrument will be upgraded to a risk class B implementation, whereas no changes are planned for OLI. With respect to the Landsat 9 project, these instruments will be referred to as OLI-2 and TIRS-2.

Landsat: Recent Accomplishments

Over the past decade, the Landsat program has achieved several notable benchmarks. First, in January 2008, the USGS and NASA decided to open the full Landsat image archive for public access on a nondiscriminatory, no-cost basis. This change in Landsat's data policy has ushered in a new era of Landsat data uses and applications while also revolutionizing the way Landsat has been woven into scientific discovery, economic prosperity, and public policy for management of land and water resources across a range of scales. Second, the Landsat Global Archive Consolidation (LGAC) initiative, an effort to recover historical imagery from past Landsat sensors archived at international cooperator ground stations around the globe, has doubled the size of the Landsat image archive on a global scale. Third, the Landsat image archive has undergone a transition to collections-based processing, which facilitates greater data traceability, accuracy, management, and distribution of analysis-ready data where image products are continuously growing and evolving. Collections also enable reprocessing of the entire archive in a systematic and transparent manner when improvements to data consistency and quality are possible (e.g., improved geometric control, updated radiometric processing).

Finally, new Landsat 8 operations revisions to Landsat's long-term acquisition plan (LTAP) have been made possible in part by OLI's notable in-orbit instrument performance and advanced imaging capabilities. LTAP applies systematic, repeatable, science-based logic to Landsat's 16-day Earth imaging of all sun-lit global landmasses and near-shore coastal regions at a solar elevation angle of greater than 5°. As Landsat's image overlap increases substantially towards the poles (to ~80%), this effective increase in temporal imaging frequency is paying important dividends for advancing our understanding of high-latitude environments, e.g., how Greenland and Antarctic ice sheets are responding to global environmental change.

For nearly two-thirds of the various Landsat missions' lifetime, there have been two satellites operating in tandem to produce eight-day revisit equivalency. At present, ~1200 Landsat images are acquired daily: ~475 from Landsat 7 (following LTAP) and ~740 from Landsat 8 (with collection of nearly all possible terrestrial land mass opportunities, due to sufficiently large onboard recording and downlink capacity). Landsat 8 alone is adding ~500,000 images per year to the USGS EROS Landsat archive. With a nominal five-year sensor design life and approximate seven-year launch readiness as guiding principles for Landsat data continuity, the upcoming launch of Landsat 9 will ensure that Landsats 8 and 9 together sustain eight-day global imaging beyond 2025.

The 2018–2023 USGS–NASA Landsat Science Team

The third 2018-2023 USGS-NASA LST—see *The Landsat Science Team* on page 22 to learn more about the LST—was selected and announced in late 2017—see **Table 1** for a list of principal investigators (PIs) and their affiliations.[2] For the 2018-2023 term, the LST will address five primary Landsat program topics, which include:

- Overseeing the end of the Landsat 7 mission and ETM+ science imaging;[3]
- overseeing the launch of Landsat 9 and evaluating OLI-2 and TIRS-2 data quality and potential science impacts;
- continuing to contribute to the process of defining science requirements for future Landsat sensors and missions;
- continuing to provide feedback on data product improvements as well as interoperability with data from other Earth-observing missions; and
- continuing to communicate the role of Landsat in understanding global land surface change and management of land and water resources.

Table 1. The 2018-2023 USGS-NASA Landsat Science Team.

Principal Investigators (PIs)	Affiliations
Martha Anderson	U.S. Department of Agriculture's (USDA) Agricultural Research Service (ARS)
Feng Gao	USDA ARS
Noel Gorelick	Google
Matthew Hansen	University of Maryland, College Park
Sean Healey	U.S. Forest Service
Patrick Hostert	Humboldt University of Berlin
Justin Huntington	Desert Research Institute
David Johnson	USDA's National Agricultural Statistics Service
Leo Lymburner	Geoscience Australia
Alexei Lyapustin	NASA's Goddard Space Flight Center (GSFC)
Nima Pahlevan	Science Systems and Applications, Inc.
Jean-François Pekel	European Commission Joint Research Centre (ECJRC)
Peter Strobl	ECJRC
Volker Radeloff	University of Wisconsin
David Roy	South Dakota State University
Ted Scambos	University of Colorado Boulder
Crystal Schaaf	University of Massachusetts Boston
Eric Vermote	GSFC
Curtis Woodcock	Boston University
Michael Wulder	Canadian Forest Service
Zhe Zhu	Texas Tech University

Winter Meeting

The winter meeting at USGS EROS was the first meeting of the new LST's 2018-2023 term. This two-day meeting was designed to familiarize the team members with each other, and brief them on the status and outlook of key Landsat program activities in 2018. The winter meeting objectives are summarized in the *Introduction* section of this article. The presentation content described below reflects the main elements that were addressed during the winter meeting.

The winter meeting opened with **Frank Kelly** [USGS EROS—*Director*] welcoming the new LST to the first gathering of the 2018-2023 term. He commented that LST PIs came to the meeting as individuals but would leave as a team. **Tom Loveland** [USGS EROS—*LST Co-Chair* and *Chief Scientist*] also welcomed the new 2018-2023 LST members, and then described the LST selection process; he followed with a description of Landsat's programmatic aims. Loveland reiterated that the LST should remain concentrated on the full Landsat archive and its utilization rather than approaching LST responsibilities from a single-mission perspective. He stated that the LST should work to expand Landsat's scientific impact and broaden its constituency. The LST team then acknowledged and applauded Loveland's years of dedicated service to the Landsat program and LST. Loveland confirmed his planned retirement from the USGS in March 2018, and then stated that **Christopher Crawford** [ASRC Federal/contractor to the USGS EROS—*Landsat Deputy Project Scientist* and *LST Co-Chair* (as of April 2018)] would transition into his LST co-chair role after working together on LST leadership activities since March 2017.

With the start of the new 2018-2023 LST, **Jeff Masek** [NASA's Goddard Space Flight Center (GSFC)—*LST Co-Chair* and *Landsat 9 Project Scientist*], who has served on four Landsat science teams starting with the

[2] The accomplishments of the second (2012–2017) LST are summarized in a sidebar called "The Legacy of the Second (2012–2017) Landsat Science Team," which appears in the May–June 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 3**, p. 22]— *https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/May%20June%202017%20color%20508.pdf#page=21*.
[3] The Landsat 7 observatory is running low on fuel, so performing an inclination maneuver to maintain ETM+'s science imaging orbit past July 2021 is no longer an option.

The Landsat Science Team

As information needs proliferate and Landsat program elements became increasingly complex, the USGS, NASA, and other partners needed a mechanism to solicit feedback and gather informed advice on the Landsat program. To meet this need, the USGS created an advisory panel, the LST, that is cochaired by the USGS and NASA. The first USGS–NASA LST was constituted in 2006, followed by recompetes for membership in 2012 and 2017. The LST is composed of competitively selected principal investigators (PIs) through a peer-review process that draws from U.S. federal government agencies, universities, and the international community. LST members serve five-year terms and participate in a minimum of two science team meetings per calendar year. The LST meetings are organized around USGS and NASA agency briefings pertinent to Landsat programmatic priorities and directions, status updates on mission operations, data archive management and processing, calibration/validation activities, data product evolution, and topical content requiring deliberation, scientific advancements, and external recommendations. Unique to the LST forum, members share their experiences, insights, and scientific findings based on use of Landsat data at each meeting via oral presentations.

LST membership is a highly sought appointment and carries significant scientific and technical evaluation responsibilities to the Landsat program. LST measures of success include Landsat scientific innovation, productive and original scientific work (documented through citable publications), the ability to enhance Landsat's science and engineering capabilities, and contributions to future Landsat sensor and mission planning. LST members are expected to bring visibility to and promote the Landsat program across a broad range of scientific and application forums. LST members are and will continue to play an increasingly important role in defining interoperability standards for Landsat and other Earth-observing systems, while exploiting their Landsat-related research as PIs to inform requirements and capabilities for the next generation of Landsat sensors. The expectation is that this role will continue throughout the next decade and should remain central to the Landsat program basis and USGS-NASA partnership.

1996-2001 NASA Landsat 7 science team, assumed the NASA LST co-chair role taking over for **Jim Irons** [GSFC—*Director of the Earth Sciences Division*] who co-chaired the prior two USGS–NASA LSTs' with Tom Loveland. Masek encouraged the LST to look more broadly at the satellite land remote sensing landscape and work to reduce roadblocks for data usage. He emphasized the importance of sensor cross-calibration as well as exploitation of the TIR time series from Landsats 4-8 (a new USGS Landsat science data product). He reinforced Loveland's comments on prior LST accomplishments, and highlighted the fact that the LST has been behind many Landsat program advancements.

Tim Newman [USGS's National Land Imaging (NLI) Program—*Program Coordinator*] gave a Landsat status briefing from a USGS management perspective. He described how the USGS and its science strategy falls within the U.S. Department of Interior's (DOI's) organizational structure, as well as its responsibility for managing 20% of the U.S. land area. Newman articulated USGS science priorities for 2018 and beyond, and discussed how the NLI program and Landsat fit into and will inform that framework. The USGS currently has a strong emphasis on integrated predictive science for the twenty-first century that will focus explicitly on natural resource decision making; land and water management; and protection of public safety, health, and property. Newman underscored several NLI programmatic challenges including securing consistent funding for Landsat development, operations, and science; maintaining operational Landsat continuity; institutionalizing the NASA-USGS Sustainable Land Imaging (SLI) program; and maturing the requirements process to meet end-user satisfaction and federal civil community needs. He concluded by briefly mentioning planning activities for the Landsat 9 follow-on Architecture Study Team, requesting that the LST start thinking about how to leverage an existing and growing commercial image data stream to augment Landsat science and applications, and for the LST to remain active in providing guidance to the NLI and Landsat programs.

Doug Daniels [USGS EROS/Aerospace Corp.—*Landsat Mission Manager*] gave a status briefing to the LST on Landsat 7 and Landsat 8 mission operations. There has been no change to the Landsat 7 observatory status or performance since the last LST in July 2017.[4] Daniels mentioned the NASA Restore-L servicing mission[5] to refuel Landsat 7 and said the USGS is working to understand the proposed strategy. He also briefly reviewed the Landsat 7 end-of-mission timeline, highlighted earlier in this article. The Landsat 8

[4] A summary of the Summer 2017 Landsat Science Team meeting can be found in the January–February 2018 issue of *The Earth Observer* [**Volume 30**, **Issue 1**, pp. 21-25—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/Jan_Feb_2018_color508_0.pdf#page=4*].

[5] The RESTORE-L mission is intended to demonstrate technologies for on-orbit rendezvous with inspection, repair, and refueling of a client satellite (Landsat 7 has been chosen as the target), all of which are vital for a future satellite servicing capability.

observatory has also experienced no change in status or performance, but did achieve the fifth anniversary of its launch on February 11, 2013.

Chris Engebretson [USGS EROS—*Landsat Science Data Processing Engineer*] reviewed Landsat archive statistics, Landsat Collection One status, Landsat Collection Two definitions and baselining efforts, and Landsat MSS 1-3 alignment with Landsats 4-8, and LGAC status. During Landsat Collection One processing, there were many Landsat TM and ETM+ scenes that had never undergone Level-1 processing. As a result, a shutter intrusion anomaly was identified in TM and ETM+ imagery appearing as what is referred to as *caterpillar tracks*. Engebretson summarized USGS efforts to understand, mitigate, and flag this data anomaly in Landsat quality assurance information during future collection-based reprocessing of the Landsat archive.

Brian Markham [GSFC—*Landsat Calibration Scientist*] gave an overview on Landsat cal/val activities and data usage recommendations, and provided Landsat 8 calibration and Landsat 9 performance updates. He described how Landsats 4-8 calibration is radiometrically tied to OLI's reflectance-based calibration. The MSS 1-3 calibration is being finalized by South Dakota State University (SDSU) and will be consistent with the Landsat 4-8 calibration. Markham stated that Landsat's radiometric uncertainty has been quantified in units of reflectance by sensor using desert pseudo-invariant calibration site (PICS) targets. Radiometric uncertainty has also been quantified for Landsats 4-8 TIR measurements using water as the calibration target. He pointed out that Landsat 8 OLI and TIRS continue to exceed radiometric and geometric expectations, with very stable on-orbit performance despite impacts of stray light on TIRS (i.e., band 11), which has been mitigated for using a postlaunch correction. For Landsat 9, OLI-2 and TIRS-2 instrument testing will follow similar protocols for OLI and TIRS, although OLI-2 spectral testing will be laser-based rather than monochromator-based, and TIRS-2 will undergo more extensive stray-light testing.

Dennis Helder [SDSU/USGS EROS—*EROS Calibration Center of Excellence (ECCOE) Director* and *Acting Landsat Calibration and Validation Manager*] presented information regarding the purpose of ECCOE and results from the first ECCOE cal/val workshop aimed at Landsat 8 and Sentinel-2 interoperability. ECCOE's vision is to be recognized as a leading national and international institution for improving the accuracy, precision, and efficiency of radiometric and geometric calibration and cross-calibration of optical remote sensing systems, to achieve the highest degree of data product interoperability. The first ECCOE cal/val workshop on Landsat 8 and Sentinel-2 interoperability was held at the PECORA20 meeting in November 2017. The workshop included a panel of experts from NASA, USGS, and European Space Agency (ESA) cal/val teams, as well as several LST members and international partners. Most of the proceedings from this workshop were made available to the broader remote sensing community.

Brian Sauer [USGS EROS—*Landsat 9 Project Manager* and *Landsat Development Manager*] offered an overview of Landsat 9 development status. Landsat 9 is a NASA–USGS partnership where NASA is responsible for the space segment, mission integration, launch, and on-orbit checkout, while the USGS is responsible for the ground system, flight operations, and data processing and distribution. Sauer summarized how Landsat 9 instrument development is progressing rapidly, with planned spacecraft integration in 2019. The Landsat 9 project has been making excellent progress against an aggressive development schedule with launch targeted for December 2020, and has been receiving high marks at each spacecraft, ground system, and mission-level review.

During the meeting, LST members had the opportunity to give oral presentations on their proposed Landsat science program contributions for the 2018-2023 term—see **Table 2** on page 24. To conclude the winter meeting, the LST reviewed prior achievements of the 2012-2017 LST, with an eye towards transition and setting new goals for the next five years. During the meeting, **Curtis Woodcock** [Boston University] and **David Roy** [SDSU] were elected by their fellow members as co-leads of the LST.

Summer Meeting

The summer meeting at the Cooperative Institute for Research in Environmental Sciences (CIRES) on the campus of University of Colorado Boulder was the second meeting of the current LST's term. This meeting offered an opportunity for the team to learn about the status of the DOI's requested review of the Landsat data policy, plans for Collection Two processing of the Landsat archive in preparation for Landsat 9 launch, and to firm up key LST recommendations for Landsat 10 and beyond, to support Landsat's next architecture study. Specific meeting objectives are outlined in the *Introduction* section of this article. The presentation content below is intended to describe the core elements of the summer meeting and to reduce redundancy in information provided for the winter meeting section of this article.

Waleed Abdalati [University of Colorado Boulder—*CIRES Director*] and **Ted Scambos** [University of Colorado Boulder—*National Snow and Ice Data Center (NSIDC)* and *LST Member*] opened the summer meeting by welcoming the LST to CIRES. In his opening remarks, Abdalati reiterated the importance of Landsat and the LST to both science and USGS–NASA agencies, emphasizing the need to turn data into value. **Christopher Crawford** and **Jeff Masek** also welcomed the LST to the second meeting of the 2018-2023 term, and briefly reviewed the summer meeting's objectives.

Table 2. Winter Landsat Science Team member presentations.

LST PI	Presentation Title*
Martha Anderson and Feng Gao	Characterizing Crop Water Use, Phenology, and Yield at Field Scales Using Multisensor Data Fusion
Noel Gorelick	Driving Cloud-Based Usage of Landsat with Google Earth Engine
Matthew Hansen	Generating Time-Series Maps that Accurately Reflect Land Change Area: A Strategy for Global Land Monitoring
Sean Healey	Landsat Science and Applications in the U.S. Forest Service
Patrick Hostert	Synergies Between Future Landsat and European Satellite Missions, from Land Cover to Land Use
Justin Huntington	Towards the Development and Integration of Landsat Evapotranspiration Ensembles and Climate Data for Enhanced Water and Land Management Decision Support
David Johnson	Leveraging Analysis-Ready Landsat Products for Use in Crop Production Estimation
Leo Lymburner	Digital Earth Australia
Alexei Lyapustin	Advanced Atmospheric Correction of Landsat 8/Sentinel-2 Data Using the Multiangle Implementation of Atmospheric Correction (MAIAC) Algorithm
Nima Pahlevan	Landsat/Sentinel-2 Constellation for Monitoring Aquatic Systems Across the U.S.
Jean-François Pekel and Peter Strobl	Copernicus–Landsat Convergence, Architecture, and Applications
Volker Radeloff	Landsat Data for Biodiversity Science and Conservation
David Roy	Pathfinding Near-Real-Time, Moderate-Resolution, Land-Surface Monitoring: Looking Forward to an Operational Landsat 9/10 Sentinel-2A/2B Era
Ted Scambos	Landsat and the Cryosphere: Tracking Interactions Between Ice, Snow, and the Earth System
Crystal Schaaf	Global 30-m Snow and Snow-Free Land Surface Albedo from Landsat and MODIS/VIIRS
Eric Vermote	Maintenance and Refinement of the Land Surface Reflectance Code (LaSRC) for Landsats and Sentinel-2s
Curtis Woodcock	New Opportunities Using the Landsat Temporal Domain: Monitoring Ecosystem Health, Condition, and Use
Michael Wulder	Integrating Time and Space with Landsat to Learn from the Past, Monitor the Present, and Prepare for the Future
Zhe Zhu	Toward Near-Real-Time Monitoring and Characterization of Land-Surface Change for the Coterminous U.S.

*Some of these presentations were given by a co-investigator on the PI's research team.

Eric Ianson [NASA Headquarters—*Associate Director for Flight Programs*] presented a broad overview of NASA's Science Mission Directorate and its satellite mission portfolio. He then described missions specific to NASA Earth Science and summarized NASA's plans to address recommendations from the 2017 Decadal Survey.[6] He emphasized Landsat 9's role in SLI to ensure continuity of the 46+ year Landsat record, and then highlighted that the SLI program constitutes 8% of NASA's flight program budget that includes advanced technology investments and demonstrations as well as full instrument concepts to inform Landsat's next architecture.

Tim Newman provided an update on the USGS's NLI priorities and highlighted that the NASA–USGS Landsat 10 Architecture Study Team (AST) that will soon kick off is the highest 2018-2019 programmatic priority. He articulated how the Landsat 10 AST would draw from a variety of information sources on requirements and capabilities to address Landsat science and application user needs, and then confirmed his commitment to measurement continuity and backwards compatibility with the Landsat archive. Newman concluded by mentioning that the Landsat 10 AST would be considering a trade space that leverages existing international satellite systems and commercial small- and cube-satellite concepts.

[6] The 2017-2027 Decadal Survey for Earth Science and Applications from Space (ESAS 2017) is intended to help shape science priorities and guide agency investments into the next decade. The survey, sponsored by NASA, NOAA, and the USGS, is driven by input from the scientific community and policy experts. To read the report, visit *http://sites.nationalacademies.org/DEPS/ESAS2017/index.htm*.

Frank Avila [National Geospatial Intelligence Agency (NGA)—*Senior Scientist* and *Landsat Advisory Group (LAG) Chair*] provided an update on the LAG's efforts to evaluate the potential for fee recovery for Landsat data use at the request of the DOI. The LAG provides advice to the federal government through the Department of the Interior's National Geospatial Advisory Committee (NGAC) on requirements, objectives, and actions of the Landsat program. In the past, the LAG has authored several reports on the value of Landsat data (see *www.fgdc.gov/ngac/key-documents*). Currently, the LAG is exploring a variety of cost-sharing models for access to Landsat data in addition to retaining the free and open data policy. Avila mentioned that USGS conducted a study on Landsat users' willingness to pay for data access, including a dollar value assignment per image. This earlier work is being revisited as part of the LAG's fee-recovery evaluation activities. The LAG expects to have a final report on Landsat data-fee recovery recommendations by spring 2019.

After Avila's presentation, the LST discussed Landsat's data policy. An important point that came up was that NASA does not charge for its Earth observation data and thus, if Landsat's current data policy was to change, it would be the only Earth observation data source with an associated access fee. The LST will draft an official position on Landsat's data policy. During the meeting's science presentations, each LST member was asked to address the importance of free and open data for their PI research and for their respective science and application community.

On the second day, **James Reilly** [USGS—*Director*] attended the meeting and took the opportunity to introduce himself to the LST by offering a short biography about his Landsat experience and awareness of its value to Earth Science. LST members had the chance to introduce themselves individually to the Director, noting their institutional affiliations and Landsat areas of expertise.

Del Jenstrom and **Brian Sauer** gave a brief update on the status of the Landsat 9 development schedule. Key takeaways were that the launch date has been set for December 15, 2020, and that the final ground system critical design review is scheduled for September 2018.

Dennis Helder reported on outcomes from the Landsat Science Interface Panel (SIP) meeting that occurred on August 7, 2018, at CIRES, prior to the LST meeting. The Landsat SIP is intended to improve communication between different elements of the Landsat program by bringing together Landsat cal/val, project science, and a subgroup of LST members to address emergent issues that crosscut cal/val and science domains. The SIP discussed the status of efforts to gain access to the Sentinel-2 global reference image (GRI) to improve Landsat 8's geodetic registration. They also discussed temporal latency challenges for distribution of Landsat 8 TIRS surface temperature products. Currently, two algorithms are under consideration: a single-channel inversion based on model radiative transfer and Modern-Era Retrospective analysis for Research and Applications 2 (MERRA-2) reanalysis data ingest, and a split-window algorithm that exploits Landsat 8 TIRS dual channels centered at 10.8 and 12.0 μm.

Steve Labahn [USGS EROS—*Land Satellite Data Systems Manager*] provided a briefing on current plans for Landsat data product improvements as well as preparation for Collection Two processing of the Landsat data archive. It is anticipated that approximately one year after the launch of Landsat 9, there will be a need to reprocess Landsat 9 data to incorporate postlaunch calibration adjustments. While the earliest possible date for Collection Two processing to begin is September 2019, how the timelines for Collection Two processing and Landsat 9 reprocessing align is under consideration. After some discussion, the LST recommended that the timing of Collection Two processing should minimize impacts to the user community while also enabling Landsat data products to evolve and improve.

Brian Markham gave an update on Landsat 8 OLI's performance from a cal/val perspective, with an emphasis on cross-calibration results with Sentinel-2 over desert PICS. Currently, Landsat 8 and Sentinel-2A cross-calibration differences are within 1.0% for all VNIR and SWIR spectral bands except blue and coastal aerosol, which are consistent within a PICS site but less so across sites. An initial Sentinel-2A and Sentinel-2B comparison over PICS sites reflect VNIR and SWIR differences around 1% that likely translate to greater differences between Landsat 8 OLI and Sentinel-2B than Sentinel-2A.

Aaron Gerace [Rochester Institute of Technology (RIT)] gave an overview of RIT's efforts to compare TIRS single-channel versus split-window algorithms for retrieving surface temperature over both land and coastal water targets. Both algorithms exploit a global emissivity database (GED) comprised of data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on Terra and Aqua platforms, because ground-reference TIR data are sparse and often measured and integrated over broadband wavelengths that do not necessarily correspond to TIRS relative spectral response functions.

Benjamin Koetz [ESA] summarized ESA's current activities related to the Sentinel-2 program. He emphasized future Sentinel mission capabilities and efforts to develop a Landsat Surface Temperature Mission (LSTM) that is currently under consideration by the European Commission and an international advisory panel. He reiterated the importance for having close ties with the USGS-NASA Landsat program, and to continue to work towards data interoperability.

Jeff Masek provided a brief overview of NASA's MuSLI program, which is designed to exploit a range of U.S. and international Earth observation data including optical, thermal, and synthetic aperture radar measurements, to advance the remote sensing science of land cover and land-use change across multiple spatial and temporal scales. There is natural overlap between LST and MuSLI expertise, and it is anticipated that these distinct but complementary science teams will interact across a range of forums in the coming years to address key issues surrounding medium-resolution Earth observations from the Landsat-Sentinel virtual constellation.

During the meeting, LST members had the opportunity to give oral science presentations on their ongoing Landsat program contributions for the 2018-2023 term—see **Table 3**.

Table 3. Summer Landsat Science Team member presentations.

LST PI	Presentation Title*
Martha Anderson	Use of Landsat Data in Real-Time Irrigation Management—and ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) Update
Feng Gao	Values of High-Temporal and Spatial-Resolution Data for Crop Yield Assessment Over the U.S. Corn Belt Using Landsat, Sentinel-2, and MODIS
Noel Gorelick	Driving Cloud-Based Usage of Landsat
Matthew Hansen	Large-Area Land Monitoring Enabled by Freely Available, Long-Terrm Global Acquisitions of Landsat Imagery
Sean Healey	Landsat as the Wall-to-Wall Phase of a Hierarchical Global Forest Monitoring System
Patrick Hostert	Land Use 2.0: The Role of Dense Time Series and Phenometrics *(David Franz presented)*
Justin Huntington	Supporting Water and Land Management Through the Combined Use of Landsat, Climate Data, and Hydrologic Models
David Johnson	On Using the Landsat Archive to Map Crop-Cover History Across the U.S.
Leo Lymburner	Mapping the Mangroves and Intertidal Zones of the Australian Coast
Alexei Lyapustin	MAIAC Algorithm Development for Lansat 8/Sentinel-2 Processing: First Results
Nima Pahlevan	Global Long-Term Aquatic Studies with Landsat Archive
Jean-François Pekel and Peter Strobl	Aspects of Interoperability on Distributed Data Platforms
Volker Radeloff	Topographic Correction of Landsat Imagery in the Caucasus Mountains
David Roy	Land-Surface Monitoring at Long and Short Timescales
Ted Scambos	The Power of Free: Time-Series Landsat 8 Applications to Ice Sheets, Glaciers, and Snow
Crystal Schaaf	Landsat Albedo of Higher Latitudes *(Angela Erb presented)*
Eric Vermote	Maintenance and Refinement of the LaSRC for Landsats and Sentinel-2s
Curtis Woodcock	Time Series, Time Series, and More Time Series
Michael Wulder	Quantifying Forest Recovery: Spectral and Structural Insights from Landsat and Lidar Time Series
Zhe Zhu	Making Landsat Time Series Consistent for Monitoring Land Change

*Some presentations were given by a co-investigator on the PI's research team, as indicated.

Conclusion

The year 2018 brought about several changes to the LST configuration and the Landsat program more broadly, with successful and rapid development of the Landsat 9 mission. A new USGS–NASA LST was selected and announced for the 2018-2023 term in addition to other LST leadership transitions on both the USGS and NASA sides of the Landsat partnership. While the Landsat mission and program is arguably at its most stable point in its five-decade existence, activities in 2018 have opened new frontiers that the LST and Landsat program will need to address specifically across four core areas: Landsat 9 development, launch, and data integration; Landsat 8 and Sentinel-2 data interoperability; Landsat data product evolution and archive reprocessing; and the Landsat 10 architecture study. As always, the USGS–NASA partnership, the Landsat program, and the LST together possess the maturity and resolve to move ahead, with the understanding that measurement continuity and traceability are the most essential ingredients for the next generation of Earth observations from Landsat. ■

2018 CLARREO Science Definition Team Meeting Summary

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Introduction

The thirteenth biannual meeting of the Climate Absolute Radiance and Refractivity Observatory (CLARREO) Science Definition Team (SDT) was held at the Laboratory for Atmospheric and Space Physics (LASP), of the University of Colorado Boulder in Boulder, CO, May 16-17, 2018. Over 30 participants attended the two-day meeting, during which members of the SDT and the CLARREO management teams gave presentations on progress made in their science studies and on programmatic updates, respectively.

The first day covered presentations related to the 2007 Decadal Survey-recommended CLARREO mission.[1] The second day was devoted to presentations on CLARREO Pathfinder (CPF)—see *Evolution of the CLARREO Mission Concept* on page 30. Highlights from the meeting presentations are summarized here. For additional details, the agenda and many of the presentations can be viewed online at *https://clarreo.larc.nasa.gov/events-STM2018-05.html*.

Day 1: Overview of "Full" CLARREO Mission Studies

Bruce Wielicki [NASA's Langley Research Center (LaRC)—*CLARREO Mission Scientist*] and **Ken Jucks** [NASA Headquarters (HQ)—*CLARREO Program Scientist*] began the day with an overview and status of both the Full CLARREO and CPF missions, as well as an overview of the 2017 Decadal Survey.[2]

Wielicki informed the team that NASA HQ has provided guidance that the Full CLARREO mission (along with all other 2007 Decadal Survey missions that remained in preformulation) will be closed out at the end of September 2018. The future of CLARREO-like infrared (IR) and radio-occultation (RO) measurements is uncertain and will depend on how NASA HQ chooses to implement recommendations from the 2017 Decadal Survey. The only work related to Full CLARREO Mission reflected solar (RS) measurements that will transfer to CPF is that which is deemed relevant to achieving the CPF mission objectives (which are specified later in this article). Additional studies using CPF measurements may be conducted by a science team potentially to be selected as a result of a future solicitation.

CLARREO scientists, engineers, and NASA Headquarters members convene at LASP to discuss science and programmatic progress made on CLARREO over the last year. **Photo credit:** Amber Richards [LaRC/SSAI]

The remainder of the day was devoted to a series of presentations on the various proposed measurements that were recommended to be part of the Full CLARREO mission and other related topics.

Radio Occultation Measurement Presentation

Stephen Leroy [Atmospheric and Environmental Research (AER)] discussed his recent study evaluating the consistency of stratospheric temperature trends determined from measurements from the Atmospheric Infrared Sounder (AIRS) on the Aqua platform, global positioning system radio occultation (GPS RO) measurements, and reanalysis. He reminded the audience that in the absence of time-dependent biases, trends of the same geophysical variable calculated from different data sources should be identical; however, Leroy showed that this is not true in some cases, such as the IR-only (AIRS) temperature retrieval, which exhibited a trend bias relative to the combined IR-microwave retreival. The presentation ended with recommendations on characterizing and mitigating the effects of such time-dependent biases on trend detection.

Infrared Measurement Presentations

Helen Brindley [Imperial College London] gave an overview of the Far infrared Outgoing Radiation and Monitoring (FORUM) Earth Explorer 9 (EE9)-candidate mission.[3] Its goal is to obtain the first-ever

[1] View the full report at *https://www.nap.edu/catalog/11820/earth-science-and-applications-from-space-national-imperatives-for-the*.
[2] The second (2017) Earth Science Decadal Survey focuses more on priority measurements than on specific missions. View the full report at *http://sites.nationalacademies.org/DEPS/ESAS2017/index.htm*.

[3] Earth Explorer missions fall under the European Space Agency's Living Planet Programme. For more information, visit *http://www.esa.int/Our_Activities/Observing_the_Earth/The_Living_Planet_Programme/Earth_Explorers*.

measurement of the entire IR spectrum from space—including the far-IR—with high radiometric accuracy. The FORUM team is working to educate the scientific community regarding how the information from FORUM could help in their scientific studies.

Hank Revercomb [University of Wisconsin-Madison, Space Science and Engineering Center (SSEC)] followed with a presentation on the need for a CLARREO-like IR instrument to serve as an absolute reference, based on his experience with the growing international fleet of operational sounders.[4]

Fang Pan [Science Systems and Applications, Inc. (SSAI)] shared her improvements on retrievals of temperature and water vapor change from temporally and spatially averaged infrared spectra simulated using the Principal Component Analysis-Based Radiative Transfer Model to emulate AIRS spectra. She showed that the retrieval results compared well with temperature and water vapor profiles from the MERRA reanalysis over the same time period during which the spectra were simulated.

Xianglei Huang [University of Michigan] reported on his studies using AIRS and the Atmospheric Radiation Measurement Southern Great Plains (ARM SGP) clear-sky radiance observations and Level 2 retrievals to evaluate meteorological reanalyses. He found sufficiently small differences between AIRS and the ARM SGP site measurements such that both could be used to quantify European Reanalysis (ERA)-Interim and MERRA biases.

Reflected Solar Measurement Presentations

Xu Liu [LaRC] discussed his work on validating his team's Principal Component-based Radiative Transfer Model (PCRTM) output spectra with the LASP HyperSpectral Imager for Climate Science (HySICS) balloon flight data. HySICS forms the basis for the design of the CPF spectrometer.

Richard Xu [University of Iowa] followed with his results from using information-content analysis to quantify the information gained by using additional spectral bands when retrieving aerosols above clouds, using hyperspectral measurements of reflected solar radiation. His novel technique showed an improvement in retrieving additional pieces of information about scenes that include aerosol over cloud including smoke *refractive indices* (a measure of absorption), smoke particle size, and smoke layer height.

[4] To learn more about NASA's participation in the international sounding community, see "Overview of 2017 NASA Sounder Science Community Activities" in the March–April 2018 issue of *The Earth Observer* [**Volume 30**, **Issue 2**, pp. 12-16—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/Mar_Apr_2018_color%20508_0.pdf#page=12*]. See pp. 12-13 for discussion of international sounder assets.

Yolanda Shea [LaRC] provided an update to her efforts to determine large spatiotemporal-scale measurement and retrieval algorithm requirements needed to detect long-term trends in cloud properties. Her results showed that reducing measurement uncertainties in the 0.65 μm and 11 μm bands, to levels similar to what the Full CLARREO mission would provide, would contribute to reducing cloud property trend uncertainties—and therefore climate sensitivity—several decades faster than using today's cloud imagers alone. Shea introduced the team to her new study on evaluating the impact of cloud retrieval bias trends on our ability to detect trends in cloud properties using satellite data.

Peter Pilewskie [LASP], speaking on behalf of **Logan Wright** [LASP], closed out the RS presentations with an overview of Wright's work on developing hyperspectral retrievals of atmospheric and surface properties from hyperspectral imagery using informed nonnegative matrix factorization. Retrieval techniques such as this could be further improved and potentially applied to future CPF spectra to retrieve atmospheric, cloud, and surface properties from space.

Other Presentations

Dan Feldman [Lawrence Berkeley National Laboratory] showed how *pan-spectral* (spanning the shortwave and IR spectral ranges) climate Observing System Simulation Experiments (OSSEs)[5] that have been conducted to simulate CLARREO observations could be used to more rigorously identify observation needs from the large number of Model Intercomparison Projects (MIPs) that have been endorsed for the Coupled Model Inter-comparison Project, Phase 6 (CMIP6).

Peter Pilewskie recapped his team's work and successes on the recently launched Total and Spectral Solar Irradiance Sensor (TSIS-1), which is installed on the International Space Station (ISS). In addition to the success of TSIS-1 being a boon for the team at LASP and the climate community at large, its success is also exciting news for the CPF mission because TSIS-1 will assist the CPF spectrometer in its calibration efforts using the sun.

Day 2: CLARREO Pathfinder Mission

The second day's focus was on CPF. There was an overview of the mission and a progress update, followed by a series of technical presentations that focused on the progress being made toward fulfilling the mission's two objectives, as stated below.

[5] Climate OSSEs emulate instruments, like CLARREO, that monitors Earth's climate fluctuation and trends using climate model output.

Mission Overview and Progress Update

Gary Fleming [LaRC—*CPF Project Manager*] presented an overview of the mission and its status. The CPF mission is designed to fulfill these two specific objectives:

1. Demonstrating, through in-orbit calibration, the ability to make high-accuracy [uncertainty ≤ 0.3% (k=1)], *Système international d'unités* (SI)-traceable measurements of Earth's solar reflectance.

2. Demonstrating the ability to transfer this high accuracy to other in-orbit assets by intercalibration [uncertainty ≤ 0.3% (k=1)] with the Clouds and Earth's Radiant Energy System (CERES) on Terra and Aqua, and the Visible Infrared Imaging Radiometer Suite (VIIRS) on the Joint Polar Satellite System (JPSS-1)—see **Figure 1**.

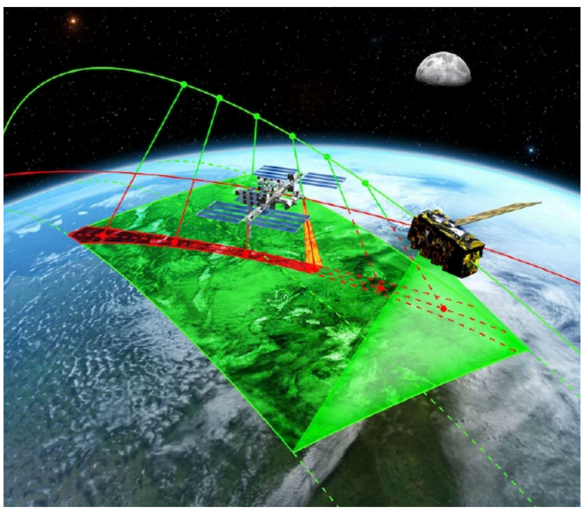


Figure 1. The diagram illustrates mission Objective 2. As the ~409-km ISS orbit (black line) passes under the 824-km orbit of the first JPSS-1 (higher, white line) the CPF instrument on ISS collects measurements of Earth's reflected solar radiation (smaller, black area) matched in time, location, and view angle with the CERES and VIIRS instruments on JPSS-1 (larger, light shaded area). These matched measurements will be used to transfer CPF's higher accuracy to CERES and VIIRS. **Image credit:** Tim Marvel [LaRC/SSAI]

The mission's scheduled launch to the ISS is planned for late CY22. Nominally it will have a one-year mission lifetime with an additional year of funding for science data analysis.

Fleming then reminded the group of CPF's history to date. He stated that the mission was among several proposed for cancellation in the Trump Administration's FY18 budget proposal, but ultimately was included in Congressional appropriations for FY18. Subsequently, NASA HQ gave approval to proceed on the Pathfinder sole-source contract with LASP. Since the meeting in May 2018, the LASP prime-contract proposal has been received and reviewed, and negotiations are underway. The prime contract is scheduled to be awarded by the end of FY18.

Progress on Fulfilling Objective 1

Paul Smith [LASP] began the CPF technical portion of the meeting with a detailed discussion of the LASP team's work on identifying and quantifying all necessary terms of the CPF spectrometer uncertainty budget. His analysis shows that the uncertainty for a small ensemble of aggregated spectra, on average, satisfies the mission requirement of [uncertainty ≤ 0.3% (k=1)].

Kurt Thome [NASA's Goddard Space Flight Center] gave a presentation summarizing the new work to advance the Goddard Laser for Absolute Measurement of Radiance (GLAMR) system. This is part of a larger effort to enable the independent calibration laboratory and field-evaluation methods that will complement the official on-orbit CPF calibration effort led by LASP.

Progress on Fulfilling Objective 2

Constantine Lukashin [LaRC] began the intercalibration discussion with an overview and status of CPF intercalibration activities to be completed in the third and fourth quarters of FY18. Activities included prototyping the simulation of Level 1B data products, estimating angular corrections for CERES intercalibration, and prototyping PCRTM-based corrections for CPF broadband. The presentations that followed Lukashin's status overview provided more detail on most CPF inter-calibration activities. Lukashin gave a summary of work not summarized in subsequent presentations including the work the team has done on assessing the CERES point spread function code portability and the assessment of the need for angular corrections to meet the CERES intercalibration requirement of uncertainty ≤ 0.3% (k=1).

Wenbo Sun [SSAI] discussed his theoretical Polarization Distribution Model (PDM) results for summer mixed trees using an Adding Doubling Radiative Transfer Model (ADRTM). He estimates that with his ADRTM the degree of polarization of reflected shortwave radiation from summertime mixed trees can be modeled with a mean uncertainty of better than 5%, which is sufficient for Pathfinder intercalibration of VIIRS.

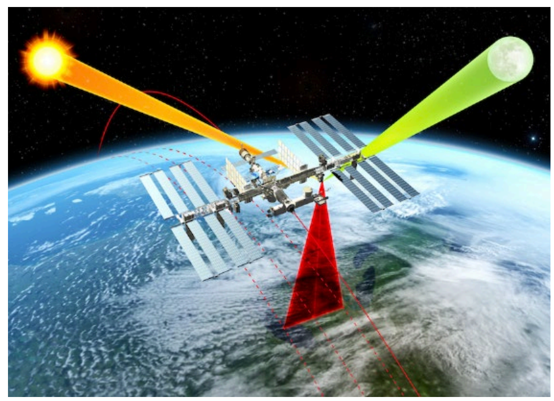
Daniel Goldin [SSAI] gave an update on his work developing empirical PDMs using Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar (PARASOL) data. He also updated the team on his work developing the PDM module that merges theoretical (from Wenbo Sun's work) and empirical PDMs for the intercalibration team's characterization of VIIRS sensitivity to polarization.

Evolution of the CLARREO Mission Concept

The first (2007) Earth Science Decadal Survey identified CLARREO as a *Tier-1* (i.e., highest) priority mission for development. The CLARREO Pre-Formulation Mission, referred to herein as the "Full" CLARREO mission, was recommended to better understand climate change. From the CLARREO website, "The foundation of CLARREO is the ability to produce highly accurate climate records to test climate projections in order to improve models and enable sound policy decisions.* The CLARREO mission sought out to accomplish this critical objective through accurate *Système international d'unités* (SI units)-traceable decadal observations that are sensitive to many of the key climate parameters such as radiative forcings, climate responses, and feedbacks. Uncertainties in these parameters drives uncertainty in current climate model projections."

The 2007 Decadal Survey outlined a mission design that included measurements of Earth's thermal infrared spectrum using an infrared (IR) spectrometer (5-50 µm); the spectrum of solar radiation reflected by Earth and its atmosphere using a reflected solar (RS) spectrometer (350-2500 nm); and temperature and water vapor profiles from radio occultation (RO) measurements.

Subsequent NASA budgets, however, zeroed out funding for the Full CLARREO mission, so it remains in Pre-Formulation (Extended Pre-Phase A) today—and is now slated to close out in September 2018, along with all other missions recommended by the 2007 Decadal Survey. However, in 2016, funding for the CLARREO Pathfinder (CPF) mission [*illustrated right*] was included in the president's budget request. CPF will demonstrate essential measurement technologies required for the Full CLARREO mission. The allocated funds support the flight of an RS spectrometer only, that will be hosted on an ExPRESS logistics carrier (ELC-1) on the International Space Station (ISS) in approximately the 2023 timeframe. This mission has been allotted funding for one year of operations followed by an additional year of data analysis.



The CPF mission mounted on the ISS will demonstrate the ability to make high-accuracy [uncertainty ≤ 0.3% (k=1)], SI-traceable measurements of Earth's solar reflectance through in-orbit calibration. This image shows two of the CPF instrument's calibration modes, in which the two-axis gimbal is used to orient the instrument to take direct measurements of the sun [*left*] and the moon [*right*], and the instrument's nadir mode, in which the instrument measures solar radiation reflected by Earth. **Image credit:** Tim Marvel [LaRC/SSAI]

* Learn more about both the Full CLARREO Mission and CPF at *https://clarreo.larc.nasa.gov/about-pathfinder.html*. For a more detailed report on CPF, see *https://clarreo.larc.nasa.gov/pdf/CLARREO_Pathfinder_Report.pdf*.

Tom Stone [USGS] highlighted the sensitivity of CPF measurements of the moon to short-term changes in lunar irradiance, which can be used to determine lunar scanning requirements.

Wan Wu [SSAI] shared his results on the development of a CPF simulator as an essential tool to generate proxy data for developing an intercalibration algorithm, one-year mission simulation studies, and data-production software testing.

Qiguang Yang [SSAI] discussed development and validation of spectrally-resolved bidirectional reflectance distribution functions (BRDF) for CPF using a novel hyperspectral bidirectional reflectance model. This work is important to expand ocean and land surface radiance from the CPF spectral range (350 nm – 2500 nm) to the CERES shortwave spectral range (200 nm – 5000 nm) for effective CERES intercalibration.

Conclusion

The team ended the meeting with a discussion on the recommendations to NASA from the Decadal Survey Steering Committee. It was clear in the report that the CPF reflected solar mission remained a part of the Program of Record that the Decadal Survey steering committee considered critical to accomplishing the necessary science objectives for the next decade. The CLARREO team discussed how this fits into the bigger picture of monitoring climate variability and change and future possibilities for a Full CLARREO-like mission. ■

Summary of the Third Surface Water and Ocean Topography Science Team Meeting

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Introduction and Mission Status

The third Surface Water and Ocean Topography (SWOT) Science Team Meeting was held in Montreal, Canada, June 26-28, 2018.[1] The meeting was immediately followed by the SWOT Hydrology Discharge Product Development Meeting, and Ocean Calibration/Validation Meeting, which both took place on June 29. All three meetings are summarized here; the agenda and presentations for the meetings are available at *https://swot.jpl.nasa.gov/meetings_agenda.htm?id=21*.

The meetings were planned and convened by the mission's science leads: **Tamlin Pavelsky** [University of North Carolina, Chapel Hill] and **Jean-François Cretaux** [Centre National de la Recherche Scientifique/Laboratoire d'Études en Géophysique et Océanographie Spatiales, France] for hydrology, and **Rosemary Morrow** [Centre National d'Études Spatiales (CNES; the French space agency)] and **Lee-Lueng Fu** [NASA/Jet Propulsion Laboratory (JPL)] for oceanography.

NASA and CNES are jointly developing and managing SWOT, with contributions from the Canadian Space Agency and the U.K. Space Agency. Now in final design and fabrication, SWOT passed its Critical Design Review (CDR)[2] earlier this year. Designs across all mission elements—systems engineering, flight, and ground systems—were brought to a state of suitable maturity for CDR, including development and testing of engineering-model hardware and software.

The majority of SWOT's flight and ground systems utilize *heritage* elements (i.e., components proven successful on previous missions). The noteworthy exceptions are the K_a-band Radar Interferometer (KaRIn)—SWOT's key technology, as illustrated in **Figure 1**—and the Science Data Processing Systems, currently in development, which implement cloud-based technologies to accommodate the large data volumes expected from KaRIn.

Development of KaRIn is steadily progressing, including development of its mast, antenna, and support structure. KaRIn's engineering models have undergone successful testing—including end-to-end radar electronics and antenna pattern analysis—and its flight modules are currently being built and tested.

In addition to KaRIn, SWOT's heritage instruments include the Altimeter, Advanced Microwave Radiometer, Global Positioning System Payload, Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS) antenna, Laser Retroreflector Array, and X-band telecommunications antenna. Flight modules for these payload components are either completed or in the final stages of construction and testing.

Science Team Overview and Major Meeting Outcomes

The SWOT Science Team is comprised of 52 investigation teams, with 22 in the U.S., 18 in France, 6 in Brazil, and 1 team in each of the following counties: Australia, Canada, Colombia, Greece, Japan, and Spain.

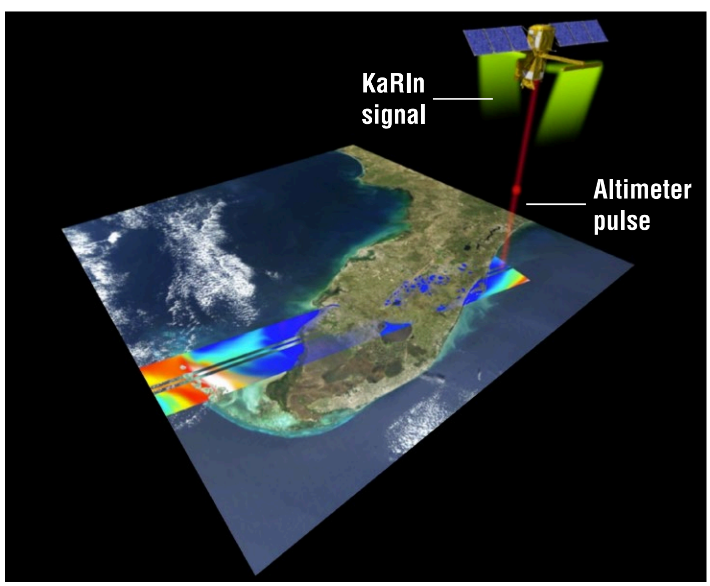

Figure 1. KaRIn's synthetic aperture radar system (SAR) will be used to determine the elevation of water surfaces on land and at sea. The white shading represents the KaRIn signal (i.e., SAR data). SAR data are shown as two relatively wide ground swaths. Between these is a narrower strip of water elevation measurements, representing data that will be collected by the nadir altimeter. The white dot in the image represents an altimeter pulse. **Image credit:** NASA/JPL

[1] The first SWOT Science Team Meeting took place June 13-15, 2016, in Pasadena, CA and was summarized in the September–October 2016 issue of *The Earth Observer* [**Volume 28**, **Issue 5**, pp. 18-23—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/Sept-October%202016%20color%20508.pdf#page=18*]. The second SWOT STM took place June 26-28, 2017, in Toulouse, France and was summarized in the September–October 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 5**, pp. 26-29—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/Sept_Oct_%202017_color.pdf#page=26*].

[2] A Critical Design review is a crucial step in development for a NASA Mission or Program. For details, see *NASA Procedural Requirements*, **7120.5D**, p. 30.

There are 25 oceanography teams, 21 hydrology teams, and 6 synergistic science teams (e.g., coastal and estuarine studies, applications, sea ice, and marine geophysics). In addition to discussing investigation teams' findings, this meeting was marked by major outcomes that will benefit the oceanography, hydrology, and synergistic sciences communities. Two of these major outcomes are summarized here.

Reduction of Latency of KaRIn Data Products

One important discussion that took place during the meeting was the SWOT Project's evaluation of reducing the latency of some KaRIn data products to less than three days. This activity was primarily in response to the needs of SWOT applications and operational users. Over the past year, the Project assessed the potential impact of adding short-latency products in terms of science algorithms, data processing workflow, and expected performance. The Project has concluded that it would able to generate routine, short-latency science products while still meeting mission requirements.[3]

Reprocessing of SWOT Data

Another significant outcome of the meeting was related to reprocessing of SWOT data. Science Team members have advocated for annual reprocessing of SWOT data, as opposed to the baseline plan of one full and one partial processing pass during the duration of the prime mission (three years). The rationale behind this request is a desire to leverage the expected evolution of science data algorithms as in-flight data become available, along with the evolution of hydrology information over time (e.g., updates to a database of global river locations and characteristics over the life of the mission—an example of one such database is described later in Figure 5). The SWOT Project concluded that annual reprocessing would be a valuable enhancement and that the products (routine and reprocessed) would be distributed by JPL and CNES.

Key Updates in Oceanography and Hydrology

During the 2018 SWOT Science Team Meeting, approximately half of the time was spent on oceanography- and hydrology-related Splinter Sessions. The objectives of these sessions are summarized in **Table 1**.

In the oceanography sessions, much of the discussion centered on potentially SWOT-relevant observations of sea surface height (SSH) at fine scales—between 10 and 100 km (6.2 and 62 mi). At these spatial resolutions, SWOT will reveal two-dimensional ocean variability as never before seen, providing deeper insight into ocean mixing caused by fine-scale fronts and eddies, including their strong impact on vertical transport between the upper ocean and deeper layers. Deciphering such small-scale exchanges is key to understanding the ocean's role in climate change.

To assess the small spatial scales that SWOT will resolve, investigators are examining the *wavenumber spectrum*[4] of SSH from past satellite altimeters and other instruments. For example, **Figure 2** shows a wavenumber spectrum based on Jason-2 SSH anomaly data. At wavelengths longer than 100 km (~62 mi), the spectrum shows power density increasing with wavelength. At wavelengths shorter than 100 km, the leveling off of the spectrum indicates the dominance of the measurement errors of Jason altimeters.

[4] Wavenumber is the spatial frequency of a wave. Whereas temporal frequency can be thought as the number of waves per unit time, wavenumber is the number of waves per unit distance.

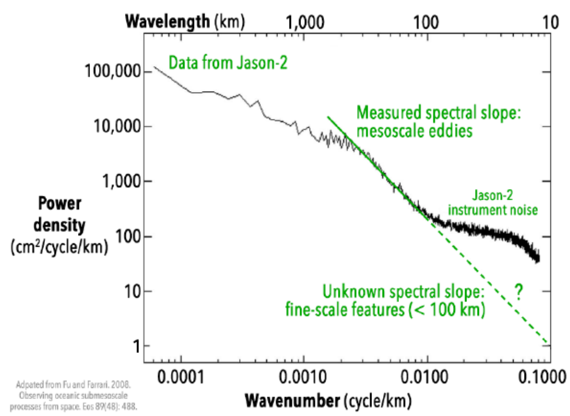

Figure 2. Spectrum of sea surface height anomaly data from the Jason-2 altimeter, sampled along a long satellite pass from the Bering Sea to Drake Passage in the Southern Ocean. At shorter wavelengths [less than 100 km (62 mi)], these data are dominated by instrument noise. The solid line represents the spectral slope associated with mesoscale eddies sampled during this altimeter pass; the dashed line projects the spectrum into ranges that Jason-2 cannot obtain—but that SWOT will. **Image credit:** Fu and Farrari

Table 1. Science topics of Oceanography and Hydrology Splinter Sessions.

Oceanography Session Topics	Hydrology Session Topics
Sea surface height (SSH) and currents at fine scales [less than 100 km (62 mi)]	Coordination of SWOT calibration/validation activities among international partners
High-resolution ocean general circulation models	*A priori* datasets and algorithms
Reconstruction of SSH and upper-ocean circulation	Hydrology data products (i.e., pixel cloud, river and lake data products, raster data products)
Representing tides and internal tides in models	Hydrological and hydrodynamical models
Ocean calibration/validation and *in situ* validation experiments	Data assimilation studies and cycle average (i.e., multiple swath) products

[3] The current best estimate of the hydrology height errors for the higher latency products is 5.7 cm (2.2 in) over 1-km^2 (0.39-mi^2) areas (as opposed to 5.4 cm (2.1 in) for the nominal 45-day latency products); no change in hydrology slope error; and negligible impact on sea surface height spectrum requirements.

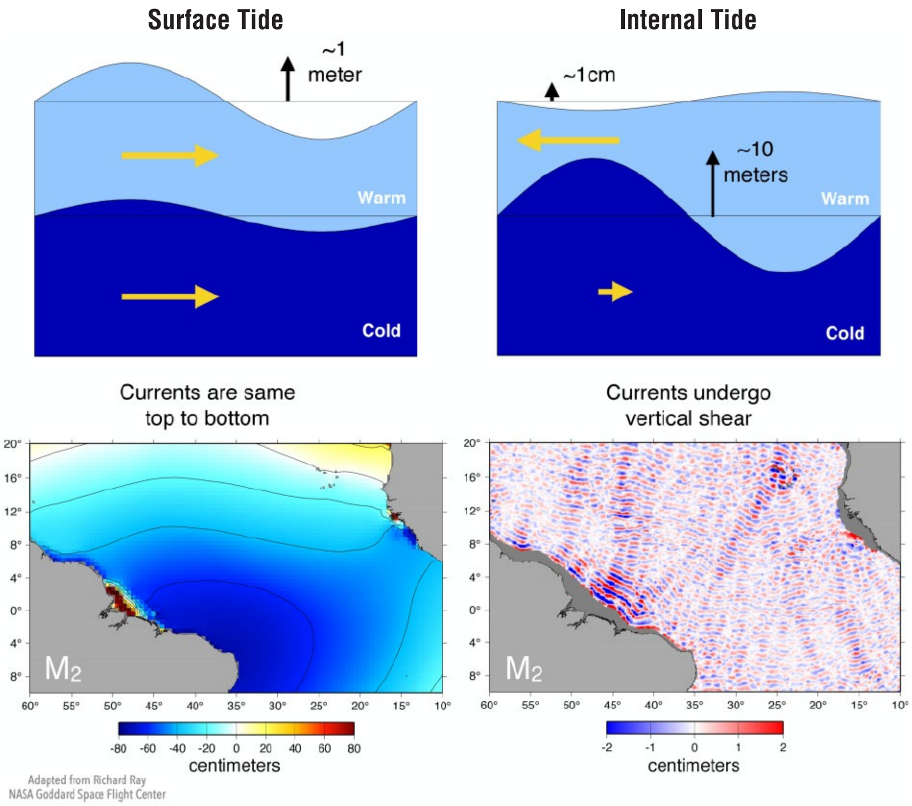

Figure 3. *Upper panels*: Cross-sectional depiction of surface tides [*left*] and internal tides [*right*]. Surface tides change sea level about 1 m (3.3 ft) in the open ocean. They have been modeled well using altimetry data. Internal tides are complicated by vertical shear in the ocean; they change sea level a few centimeters in the open ocean. It is anticipated that SWOT will be able to observe SSH caused by internal tides. *Lower panels*: Snapshot views showing associated SSH impacts of one tidal constituent (M_2) in the Atlantic Ocean (South America is at lower left; Africa is at upper right). **Image credit:** NASA's Goddard Space Flight Center

The finer scale SSH data to be obtained by SWOT will also include some high-frequency signals that present both an opportunity and challenge for oceanographers. The decades-long record of SSH from ocean altimeters (e.g., TOPEX/Poseidon and the Jason series) has been combined with computer models that can reliably predict surface tides with high accuracy, particularly between the latitudes covered by these missions (66° N to 66° S). However, as opposed to surface tides that alter SSH on the order of 1 m (3.3 ft) in the open ocean, internal tides create complicated fine-scale signatures while affecting SSH by only a few centimeters—see **Figure 3**. The SWOT orbit was chosen to mitigate some internal tide issues; nonetheless, many members of the Science Team are using high-resolution, high-frequency ocean general-circulation models and other methodologies to develop approaches to deal with internal tides and other high-frequency motions in SWOT SSH data.

For hydrologists, a key update delivered during the meeting concerned a comprehensive verbal report[5] on a study carried out by JPL on possible *layover* impacts on SWOT data, an item of potential concern. Layover in SAR data occurs when topographic variations cause multiple radar pulse echoes from different parts of a target surface to arrive simultaneously at a receiver, thus becoming indistinguishable from one another—see **Figure 4**. Layover is largely determined by viewing geometry and cannot be feasibly mitigated by changes in instrument hardware or algorithm design. Moreover, assessing layover impact on continental-to-global scales through direct simulation is not possible because of a lack of high-fidelity digital elevation models (DEMs). Instead, using available DEMs, scientists and engineers from JPL developed and validated a conceptual model for predicting layover errors in SWOT data as a function of topographic variability. Members of the Science

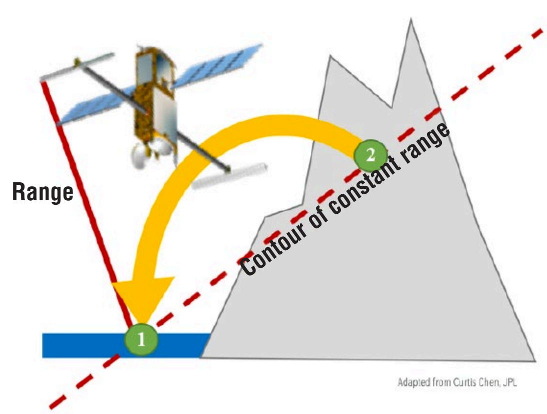

Figure 4. *Depiction of KaRIn layover issue.* (1) Desired radar echo from water surface (intersection of solid and dashed lines near arrowhead) could arrive simultaneously with (2) undesired echo from high topography (intersection of the dashed contour line of constant range and end of the curved arrow). In this case, the desired and undesired echoes would be indistinguishable from one another. The arrow indicates how data from position (2) can appear to be "laid over" data from position (1). **Image credit:** NASA/Jet Propulsion Laboratory

[5] To view slides from this report, visit *https://spark.adobe.com/page/RoNb1GpyhcBsJ*.

Team then implemented this model globally. Key findings from the study showed that:

- Layover will cause primarily random errors (i.e., biases will be small);
- magnitude of errors due to layover will be significant at times but rarely dominating (since, in SWOT data, land is usually much darker than water);
- layover errors will vary geographically (i.e., from site to site); and
- overall, layover effects will be widespread but with relatively low magnitude.

Another important outcome for hydrology was the participation of AirSWOT—an aircraft-mounted interferometer meant to simulate SWOT—in NASA's Arctic-Boreal Vulnerability Experiment (ABoVE)[6] campaign. This calibration/validation effort was conducted during summer 2017, with AirSWOT collecting data over 28,000 km (17,400 mi) of flight lines in the U.S. and Canada. These data included observations of over 40,000 Landsat-observable water bodies, providing valuable scientific insights into anticipated SWOT capabilities and error characteristics.

Good progress is being made toward global-coverage river and lake *a priori* datasets, which are needed to facilitate analysis of raw SWOT data. The datasets are expected to be finalized in about two years. Results from the current database of large rivers, Global River Widths from Landsat (GRWL), were recently published in *Science*—see **Figure 5** for an example of GRWL output. Co-authored by SWOT Hydrology Lead **Tamlin Pavelsky**, the study determined that global river and stream surface area is about 45% greater than indicated by previous studies. These findings may change our understanding of the importance of streams and rivers in exchanging greenhouse gases with the atmosphere.

Next Steps

In anticipation of launch in 2021, the third SWOT Science Team Meeting demonstrated a high degree of coordination and interaction among the investigation teams and with SWOT Mission staff members across the participating countries. Many activities over the next year will focus on calibration/validation efforts, including ocean field campaigns located at targeted SWOT orbit cross-over locations. In parallel, efforts to assess relevant global oceanographic and hydrodynamic computer models, simulate (and then assimilate) SWOT observations, refine data-processing algorithms (e.g., lake-storage change, ice flagging) and products, and engage potential SWOT data users will continue in earnest.

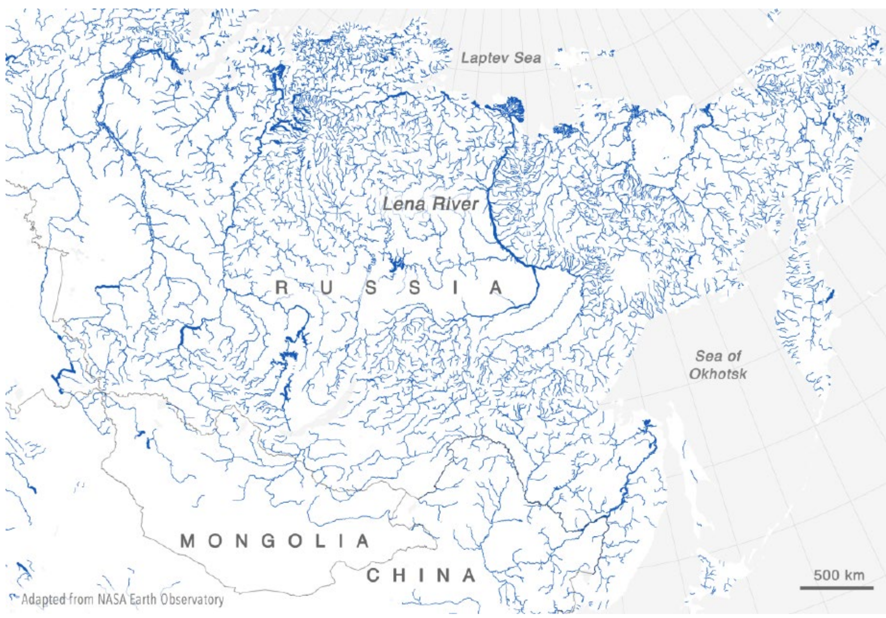

Figure 5. GRWL database plot for northeastern Asia. In this image, the width of a river—for example the Lena River in Russia—is depicted by the width of the line. Most of the area of a river network is comprised of smaller tributaries that feed the main stem. **Image credit:** NASA's Earth Observatory

The next SWOT Science Team Meeting will likely be held in Europe during the last two weeks of June 2019. ■

[6]ABoVE is a NASA Terrestrial Ecology Program field campaign in Alaska and Western Canada. ABoVE is a large-scale study of environmental change and its implications for social-ecological systems. To read about the most recent ABoVE Science Team meeting, see the May–June 2018 issue of *The Earth Observer* [**Volume 30, Issue 3**, pp, 28-30—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/May-June%202018%20color%20508.pdf#page=28*]. To learn more about ABoVE, visit *https://above.nasa.gov*.

Summary of the 2018 NASA LCLUC–SARI International Regional Science Meeting

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Introduction

South and Southeast Asian countries account for more than 25% of the global population. The annual population growth rate (averaged across all the countries in the area)[1] is ~1.25% per year. This rapid rate of growth is coincident with rapid economic development, which has led to substantial land-use change (e.g., the conversion of forested areas to agriculture and agricultural areas to residential and urban uses) in this area, which in turn has a significant impact on the environment. Further, increased land-cover and land-use changes (LCLUC) in the region are impacting forest resources, biodiversity, regional climate, biogeochemical cycles, and water resources. To address the LCLUC issues in the framework of NASA's South/Southeast Asia Research Initiative (SARI), an international science meeting was held in the Quezon City, Metro Manila, the Philippines, May 28-30, 2018.[2]

The organizers of this meeting included **Krishna Vadrevu** [NASA's Marshall Space Flight Center (MSFC), U.S.—*SARI Lead*], **Garik Gutman** [NASA Headquarters, U.S.—*LCLUC Program Manager*], **Chris Justice** [University of Maryland, College Park (UMCP), U.S.—*LCLUC Project Scientist*], **Toshimasa Ohara** [National Institute of Environmental Studies (NIES), Japan], **Tsuneo Matsunaga** [NIES, Japan], and **Atul Jain** [University of Illinois, Urbana-Champaign, U.S.]. **Mylene Cayetano** [Institute of Environmental Science and Meteorology (IESM), University of Philippines (UP) Diliman] and **Gay Perez** [IESM, UP Diliman] served as local hosts. Eighteen other local and international organizations sponsored the event, which also served as a forum for the Global Observations of Forest and Land Cover Dynamics (GOFC–GOLD) Southeast Asia Regional Network to discuss important research needs and priorities.

In total, 202 participants from 21 different countries from Asia, Europe, and the U.S. attended the meeting—see the group photo below. Scientists from five different space agencies in the region were represented, including the Japan Aerospace Exploration Agency (JAXA), the Space Technology Institute of Vietnam and Vietnam National Space Center (VNSC), the Indian Space Research Organization (ISRO), the Geo-Informatics and Space Technology Development Agency of Thailand (GISTDA), and the Indonesian National Institute of Aeronautics and Space (LAPAN). Representatives from several international programs also participated, e.g., the Group on Earth Observations (GEO) Global Agricultural Monitoring [GEOGLAM], GOFC–GOLD, and NASA SERVIR.[3] In total, 103 organizations were represented at the meeting. Prior to the meeting, local hosts also organized a two-day field visit to Mount Pinatubo, a volcano that erupted in June 1991, to observe how the eruption impacted local land cover and land use—see *An Excursion to Mount Pinatubo 27 Years After Its Eruption* on page 36.

[1] The countries considered part of South/Southeast Asia for purposes of this calculation are Afghanistan, Pakistan, Nepal, India, Bhutan, Bangladesh, Sri Lanka, Timore-Leste, Brunei, Philippines, Cambodia, Laos, Malaysia, Myanmar, Vietnam, Indonesia, and Thailand. Note that in the Maldives, annual population growth is negative (-0.07).

[2] The 2017 LCLUC–SARI International Science Meeting was summarized in the November–December 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 6**, pp. 40-47—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Nov_Dec_2017_color_508.pdf*].

[3] SERVIR is not an acronym; it is derived from a Spanish word meaning "to serve."

NASA LCLUC–SARI meeting participants in Quezon City, Philippines. **Photo credit:** University of Philippines, Diliman team

An Excursion to Mount Pinatubo 27 Years After Its Eruption

Mount Pinatubo is an active volcano in the Philippines. The volcano erupted explosively in June 1991, filling the neighboring areas with volcanic deposits as much as 200 m (~656 ft) deep. The eruption removed so much magma and rock that the summit collapsed to form a caldera 2.5 km (~1.5 mi) across—see *Photo*. To further complicate matters, at the time of the eruption, tropical storm Yunya passed to the northeast of Mount Pinatubo, resulting in a torrential rainfall in the region. The ash that was ejected from the Pinatubo mixed with the water in the air and caused a rainfall of *tephra* (fragments of rock from the eruption) that covered almost the entire island of Luzon, the remnants of which were visible even today. Nearly 10 cm (~4 in) of ash covered a 2000 km^2 (~772 mi^2) area.

There were other long-lasting effects caused by the eruption and consequent earthquakes, with significant physical and infrastructure effects. Even today—27 years later—travel is still problematical in some areas, and the rice yield in the region surrounding the volcano is still low.

Prior to the start of the meeting, some participants visited Mount Pinatubo and the surrounding area of Bacolor (a municipality in the Province of Pampanga) to understand the local land cover and land use issues, and the impact the 1991 eruption had on the landscape. They saw a half-buried church, and observed the vegetation changes on the lower slopes of the Luzon Mountains and lowland forests. The hill-top upper montane forests are covered with trees that are shorter in stature along with epiphytes, vines, and moss.

Lake Pinatubo formed due to the collapse of the summit of the mountain due to volcanic eruption. The lake is the deepest in the country with a depth of 600 m (2000 ft). **Photo credit:** Krishna Vadrevu [MSFC]

The first and third days of the meeting included plenary sessions on Agriculture, Atmosphere, Forests, Land, and Urban themes. The second day was devoted to in-depth parallel sessions on the Agriculture and Atmosphere themes, each having technical presentations followed by panel discussions, with time for formal discussions and ample opportunity for informal conversations. Sixty-four scientific presentations were given, along with 25 poster presentations.

The following summary presents highlights from each day of the meeting. The full agenda and all presentations are available from the LCLUC program website at *http://lcluc.umd.edu/meetings/land-coverland-use-changes-lcluc-and-impacts-environment-southsoutheast-asia-international*.

Day One

The meeting began with introductory welcome remarks followed by two thematic technical sessions with presentations on agricultural LCLUC, atmospheric correction, emission inventories, and land-atmospheric interactions.

Plenary Sessions

The meeting started with welcome remarks from the local hosts **Mylene Cayetano**, **Gay Perez**, and **Lemnuel Aragones** (all from IESM, UP Diliman). Aragones stated that IESM integrates environmental sciences and the meteorology and oceanography programs, and for the past fourteen years has served as a center of excellence in the Asia Pacific. IESM addresses the science of human impact and responses to the changing weather systems and climate, including impacts on the environment in the Philippines. Aragones remarked that the current meeting is the first NASA science meeting held on the LCLUC topic in the Philippines, and noted that regional scientists are looking forward to strengthening international collaborations in the region.

Garik Gutman then welcomed the participants. Speaking on behalf of NASA, he said that addressing LCLUC issues is of high importance for the region, and that SARI is therefore facilitating such activities. Since its inception, NASA's LCLUC program has funded over 300 projects.[4] Gutman emphasized that integrating remote sensing, biophysical, and socioeconomic data to address LCLUC issues is one of the program's priorities. **Chris Justice** welcomed the participants and explained how SARI meetings are bringing the U.S. and international scientists together to discuss the latest science in the region. **Krishna Vadrevu** highlighted ongoing SARI

[4] The activities of NASA's LCLUC Science Team parallel, and sometimes overlap, with some of what is reported here. To read a summary of the most recent LCLUC Science Team Meeting, see the July–August 2018 issue of *The Earth Observer* [**Volume 30**, **Issue 4**, pp.14-18—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/July-August%202018%20Color%20508.pdf#page=14*].

projects, stressing strong research and capacity-building needs, and encouraged participants to join the SARI initiative. **Toshimasa Ohara** also welcomed the participants and remarked that most of the local air pollution concerns are closely tied to land management; thus, integrated research is necessary.

Agricultural LCLUC and Remote Sensing

The international GEOGLAM coordination initiative is the agricultural flagship of GEO. Its vision is to use coordinated, comprehensive, and sustained Earth observations to inform decisions and actions in agriculture through a system of agricultural monitoring systems, as has been described at a previous meeting. Recently, the Earth Observations for Food Security and Agriculture Consortium (EOFSAC—recently renamed "Harvest")—newly organized by NASA to focus on agriculture—was formed with 40 collaborating entities from academia, government, and nongovernmental organizations to advance agriculture and food security applications. UMCP coordinates the Consortium (*http://www.eofsac.org*).

In support of these and other activities, the European Space Agency's (ESA) Copernicus Sentinel-1[5] is a synthetic aperture radar (SAR) mission that provides an excellent opportunity for operational rice-monitoring applications, especially in cloud-hampered tropical regions. Systematic Earth observations (e.g., from the Landsat and Sentinel series) are useful for operational purposes. For example, **Thuy Le Toan** [Centre d'Études Spatiales de la BIOsphère (CESBIO), France] and her collaborators are working in Vietnam through a project titled Georice, providing operational rice monitoring, which include rice vs. non-rice maps in near-real time for three seasons per year, and providing annual crop intensities using Sentinel-1 data.

Local scientists discussed how, in the Philippines, agriculture and fisheries sectors are vital for employment, sustenance, and the economy generally. Agriculture in the Philippines is continuously challenged due to natural hazards such as recurrent typhoons. In addition, the agriculture sector is also sensitive to tariff rates, which are significantly higher than those in the industrial and mining sectors. Land degradation due to soil erosion is also quite common. In an effort to combat this, the Philippines government is working on land reclamation programs.

Similarly, India has seen 25 drought events between 1871 and 2017, with concomitant effects on its people. To explore such effects, an operational National Agricultural Drought Assessment and Monitoring System (NADAMS) has been developed, which delivers monthly and fortnightly (two-week) district- and subdistrict-level-drought assessments for the 14 dominant agricultural states in India. The NADAMS system integrates AVHRR, MODIS, and AWiFS datasets for mapping droughts.[6]

The Asia-Rice Project is led by JAXA in collaboration with the Centre National d'Études Spatiales (CNES) and Asian space agencies and ministries of agriculture to enhance rice production estimates through the use of Earth-observing satellites. Asia-Rice is collaborating with the Association of Southeast Asian Nations (ASEAN) Food Security Information System (AFSIS) to provide rice-growth outlook maps to the GEOGLAM Crop Monitor database.

In Vietnam, the Ministry of Agriculture and Rural Development (MARD) is responsible for rural development and the governance, promotion, and nurturing of the agriculture sector. MARD generates monthly reports on crop production and conducts surveys in agriculture, forestry, and aquaculture, providing periodic summaries and updates in relevant matters. They are currently working with VNSC to utilize information derived from Earth observations. The Remote sensing-based Information and Insurance for Crops in Emerging Economies (RIICE) Project—not to be confused with RICE with one "I" mentioned earlier—is delivering rice maps, early yield forecast, production, and damage assessment for 10 provinces, including eight in the Red-River Delta and two in the Mekong Basin.

In Thailand, GISTDA has been applying geo-informatics and space technology for crop monitoring and yield estimation to support the government and local agricultural organizations. Critical agricultural outputs include crop area estimation, yield prediction, crop stress, and delivering weather and climate information.

Atmospheric Correction

Specific to the atmospheric correction of optical satellite data, the Landsat surface reflectance code (LaSRC) is mature, and a pathway toward validation, and automated quality assurance has been identified. The algorithm is generic and based on documented and validated radiative transfer code, so the accuracy can be traced, making it easier to construct error budgets.

[5] Each Sentinel mission is based on a constellation of two satellites to fulfill revisit and coverage requirements, providing robust datasets for Copernicus Services. Mentioned in this article are: Sentinel-1, a synthetic aperture radar (SAR) mission; Sentinel-2, a land-imaging mission similar in scope to U.S. Geological Survey–NASA Landsat missions; and Sentinel-3, which measures ocean surface topography, land- and sea-surface temperature, and ocean color. Learn more about the Sentinel missions at *http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview4*.

[6] NOAA-AVHRR stands for National Oceanic and Atmospheric Administration-Advanced Very High-Resolution Radiometer, which has flown/flies on a number of NOAA's Polar-Orbiting Operational (POES) satellites, the most recent being NOAA-15 launched in 1998. MODIS stands for Moderate Resolution Imaging Spectro-radiometer, which flies on NASA's Terra and Aqua platforms. AWiFS stands for Advanced Wide Field Sensor, which flies on ISRO's RESOURCESAT-1 and -2 satellites.

The incorporation of bidirectional reflectance distribution function (BRDF) correction enables easy cross-comparison among different sensors (e.g., MODIS, VIIRS,[7] AVHRR, Landsat, Sentinel-2, and Sentinel-3).

Emission Inventories

The Japanese Greenhouse gases Observing Satellite (GOSAT) is dedicated to monitoring greenhouse gases (GHG) from space; it represents a joint effort among the Japanese Ministry of the Environment (MOE), JAXA, and NIES. GOSAT was launched in 2009 and has been monitoring atmospheric carbon dioxide (CO_2) for more than nine years. The successor, GOSAT-2, will be launched in FY2018 with enhanced Earth-observation capabilities over its predecessor. GOSAT data can be used to quantify CO_2 emissions from urban areas.

The Regional Emission inventory in ASia (REAS) version 3.0 is being updated and will include bottom-up emissions inventory from anthropogenic sources for different countries for 1950 through 2015. Results from the inventory suggest that emissions increased throughout the early 2000s and reached the highest value of the measurement series in 2015. REAS is being updated for NO_x emissions. Satellite-observed NO_2 over India and Southeast Asia suggest a recent increasing trend in NO_x emissions. Studies combining bottom-up emissions inventory and modeling are vital for accurate characterization of emissions.

Land Atmospheric Interactions

An important ongoing regional project is the Seven South East Asian Studies (7-SEAS) project. As a part of the project, biomass burning, aerosol, chemical, microphysical, and radiative properties over the Indochina region have been characterized. Transport patterns of biomass burning plumes from Indochina have been identified and verified by *in situ* measurements. In several southeast Asian countries, particulate pollution from black carbon (BC) is common due to incomplete combustion. BC is a major short-lived pollutant and can warm the atmosphere regionally. Specific to Manila, Philippines, old-technology vehicles are the primary cause of BC pollution. As a result, BC concentrations in some urban areas are higher than those for India or China. Furthermore, trends in surface temperature from 1880 to the present in Southeast Asia, including the Philippines, suggest a warming trend. Also, unusually high sea surface temperature is correlated with very strong typhoons in the region. A recent example was Typhoon Haiyan (2013), which resulted in extreme damage and changes in current land cover and land use in the region.

[7] VIIRS stands for Visible Infrared Imaging Radiometer Suite, which flies on both the Suomi National Polar-orbiting Platform (NPP) and the Joint Polar Satellite System-1 (JPSS-1, which is now known as NOAA-20) platforms.

Day Two

Day-two included two different parallel sessions: remote sensing of agricultural land use and atmospheric science and land-use change. The presentations and the highlights of the panel discussion are summarized here.

Remote Sensing of Agricultural Land Use

The Agricultural Market Information System (AMIS)[8] is an interagency platform launched in 2011 by the G20, or Group of Twenty, ministers of agriculture following the global food price hikes in 2007-08 and 2010. GEOGLAM has been delivering a monthly bulletin since 2013 on current growing conditions for the four major crops (wheat, maize, soybean and rice) with operational crop assessments using Earth observations, which is published in the AMIS Market Monitor. Following the AMIS Crop Monitor example, researchers at UMCP have developed the Crop Monitor for Early Warning that provides crop conditions within countries at risk (*https://cropmonitor.org*).

In the Philippines, rice area detection and monitoring using multitemporal SAR images is being carried out as a part of the Philippines Rice Information System (PRISM) project (funded from 2014 to 2017) at the International Rice Research Institute (IRRI), in collaboration with the Philippines' Department of Agriculture and other partners. As a part of the project, data products that describe rice area, cropping intensities, flooded rice-area during floods, and droughts are being delivered. A drought index, *standardized vegetation-temperature ratio* (SVTR), derived from MODIS normalized difference vegetation index (NDVI) and land surface temperature (LST) data was used to detect and characterize agricultural drought in the Philippines with 73% accuracy. SVTR forecasts show good agreement with actual drought events.

The sugarcane industry is growing in the Philippines, and Sentinel-2 data are being used to estimate tons of sugarcane per hectare at the provincial level. For rice, SAR-based yield estimation combined with the Oryza crop-growth model (*https://sites.google.com/a/irri.org/oryza2000/about-oryza-version-3*) has an added benefit. Crop-suitability mapping using remotely sensed land cover and geographic information systems (GIS) is being carried out as a part of a nationwide project called Smarter Approaches to Reinvigorate Agriculture as an Industry (SARAI, *http://www.sarai.ph*).

In Vietnam, rice monitoring from space is led by Ho-Chi Minh City Space Technology and Application Center in collaboration with CESBIO in France and An Giang University in Vietnam as a part of the Asia-Rice

[8] AMIS provides a synopsis of major developments in international commodity markets, focusing on wheat, maize, rice, and soybeans (*http://www.amis-outlook.org*).

project and a contribution towards GEOGLAM. Data on rice crop area, yield, and production, as well as crop calendars are generated using RADARSAT, Sentinel-1, and ALOS-2[9] data from 2013 to the present.

LAPAN is developing algorithms to characterize rice paddies using multitemporal MODIS, Landsat 8, and Sentinel-1 data with 70–80% accuracy on the harvested area and 90% accuracy on paddy growth. LAPAN is also receiving land-imaging data from Himawari-8,[10] MODIS, Landsat, and SPOT,[11] as well as fine-resolution satellite data (from a variety of sources) and applying them to a variety of LCLUC applications.

ISRO is using data at several spatial resolutions from AWiFS, LISS-III, and LISS-IV[12] to map basmati rice areas in Punjab, Haryana, Uttar Pradesh, Jammu, and Kashmir provinces in India with 91.8% accuracy.

The Environmental Policy Integrated Climate (EPIC) model is a semi-mechanistic terrestrial ecosystem model useful for simulating crop biomass, yields, water use, nutrient fluxes, and soil erosion under various land use management and climate change scenarios. UMCP researchers are integrating remote sensing inputs on crop cover, crop emergence, and leaf area index data into EPIC to improve crop characterization. A forecasting framework using EPIC to produce in-season crop condition and yield outlooks is also being developed. At the University of Arizona (U.S.), time-series NDVI integrating data mining is being used for crop type mapping with 90% accuracy.

Agricultural Applications of Remote Sensing Panel Discussion

The panel was comprised of agricultural experts from academia, government, and nongovernmental organizations. The panelists were asked to identify important agricultural research needs and priorities in South/Southeast Asia.

During the discussion session that followed, panelists strongly expressed a need to establish robust crop inventory and monitoring systems using remote sensing, reflecting immediate national priorities. In support of this, documentation of best practices would be extremely useful. In several countries of South and Southeast Asia, optical remote sensing is being augmented by microwave data (e.g., Sentinel-1); thus, technical support on microwave data processing and robust algorithms are needed. At the national level, all panel members identified the need for accurate and up-to-date information on crop area, planting dates, crop condition, pest and disease occurrence, yield, production forecasting and estimation. National monitoring systems should also help individual farmers and subnational decision making. Emphasis should be on transitioning from research to applications; as the process is slow, early engagement of end users and co-development is recommended. For long-term sustainability, there is a need for a strong relationship between research and operational groups. Panelists articulated the need for highly accurate products from national monitoring systems. Research is needed on prioritizing data collection for both satellite and ground data to reduce uncertainties and also to improve yield forecasting. Collecting field validation data to support the intercomparison of different approaches is also important. All participants felt that data sharing among countries is important in order to generate consistent regional products with high accuracy, which would meet the needs of multiple agencies. Participants also identified a need for a separate workshop focusing on time-series analysis techniques and standardization of remote sensing data.

Atmospheric Science and Land Use Change

In India, there are significant uncertainties on methane (CH_4) emissions. (Methane is one of the most important GHGs as it has 28 times higher global warming potential than CO_2.) Results from integrating remote sensing data for wetlands mapping and ground-based emission measurements suggest CH_4 emissions are on the order of 3 Tg annually. In cloud-affected areas, Advanced Land Observing Satellite Phased Array type L-band Synthetic Aperture Radar (ALOS-PALSAR) data can be useful in mapping wetlands and paddy areas to estimate CH_4 emissions.

In Singapore, both urban pollution and biomass burning impact air quality. For example, black carbon (BC) accounts for about 21% of locally measured atmospheric particulates with diameter ≥ 2.5 µm ($PM_{2.5}$) concentrations in Singapore during episodes without haze. In the presence of haze, the BC contribution is only about 10%. This decrease implies that other chemical species contribute significantly to $PM_{2.5}$ levels during biomass burning episodes.

[9] These are SAR missions: RADARSAT is a Canadian Space Agency mission; Sentinel-1 was defined in footnote #3; and ALOS stands for Advanced Land Observing Satellite, also called "DAICHI" in Japanese, developed by JAXA.
[10] Himawari-8 is a geostationary satellite launched by the Japan Meteorological Agency (JMA).
[11] SPOT stands for Satellite Pour l'Observation de la Terre. It is French commercial high-resolution optical imaging Earth observation satellite system. Initially created by CNES, it is now run by Spot Image, a private company based in Toulouse, France.
[12] LISS stands for Linear Imaging Self Scanner, which, along with AWiFS (defined in footnote #3) flies on ISRO's RESOURCESAT-1 and -2 satellites.

In several cities in the Philippines, emissions from automobile exhaust contribute to largest emissions. Ground-based measurements suggest significant pollutant enhancement during the "work week"—coinciding with increased levels of vehicular traffic.

In Indonesia, there is an increase of GHG fluxes after deforestation and land use conversion to oil palm growth. Proper mitigation efforts are needed to reduce the impact of deforestation on emissions and the soil environment. Peat fires are an important source of emissions and are currently underestimated. Aerial photographs combined with field observations can help detect small-scale peat fires, including underground fires. Wireless sensor networks and the like can also help to better monitor fires. Specific to agricultural fires in India, VIIRS 350-m (~1148-ft) data can detect more fires than MODIS due to a higher spatial resolution. Thus, for emissions estimation, VIIRS products can provide improved results. Validation of VIIRS-retrieved aerosol optical depth (AOD) with data from NASA's Aerosol Robotic Network (AERONET)[13] suggests that VIIRS AOD products can capture pollution events more effectively than MODIS AOD products.

Aerosol optical thickness (AOT) data retrieved using the Advanced Himawari Imager (AHI) onboard the Himawari geostationary satellite and processed using the Non-hydrostatic ICosahedral Atmospheric Model (NICAM) developed by NIES, were quite useful in capturing AOT transport from Siberia to Japan. Multimodel intercomparison of surface ozone (O_3) and related species suggests large variation in the assimilated surface O_3 over East Asia. State-of-the-art models still overpredict summertime surface O_3 around Japan; more modeling efforts are needed. The NIES team has developed a new database of vegetation and biogenic volatile organic carbon emission factors for Japan.

The National Astronomical Research Institute of Thailand (NARIT) is involved in atmospheric measurements and research. Consistent and year-long mixing-layer-height measurements using airborne lidar in the mountain valley of Chiang Mai suggests significant enhancement of air pollution due to biomass burning aerosols. The NARIT team has also participated in the High Altitude and LOng Range (HALO) – Effect of Megacities on the Transport and Transformation of Pollutants on the Regional to Global Scales (EMeRGe) Asian Aircraft Measurement Campaign (conducted in March–April, 2018) and the data are being analyzed (*www.narit.or.th*).

Some important mitigation measures to reduce pollution in Asia include: end-of-pipe mitigation measures (e.g., desulfurization equipment), improvement in the quality of fuels from high-sulfur to low-sulfur content, improvement in energy efficiency, and drastic energy-source shifting from coal to renewables or natural gas. Integrated assessment models can aid in identifying appropriate mitigation measures for pollution reduction.

[13] AERONET is a ground-based network of sun photometers, including several in Vietnam (*https://aeronet.gsfc.nasa.gov*).

Atmospheric Science and Land Use Change Panel Discussion

The discussion session began with reports from a panel comprised of atmospheric science and land use change scientists, representing different south/southeast Asian countries. They were each asked to identify important pressing issues on air pollution including research priorities in South/Southeast Asia.

All panel members and participants agreed that air pollution is a highly complex, multifaceted problem. Emissions from transportation, industries, and biomass burning are the most common sources in this region of the world. Operational monitoring of pollutants at a high spatial and temporal resolution—integrating ground and satellite measurements—is needed to understand the pollutant characteristics and impacts on the environment. Of the different pollutants, panel members felt that $PM_{2.5}$ needs immediate attention, as this can significantly impact human health. Not every city in Asia has implemented pollutant standards; there is an urgent need to find evidence-based standards and robustly implement them. Understanding chemical speciation of $PM_{2.5}$, source apportionment, and quantifying health risks to humans through measurement and modeling are all important and will require stronger linkages between the measurement and modeling communities. Participants also emphasized the need to educate the public on pollution impacts on health, and strong enforcement of the law to curb air pollution regionally and locally. Sustainable land-use planning along with efficient fuel technologies in the transportation sector can help to mitigate air pollution. Panel members felt a stronger need for capacity building and training relating to atmospheric science, remote sensing, and air pollution in the region.

Day Three

The day began with short-presentations on panel summaries from the previous days followed by technical presentations on LCLUC in the forestry sector and urban areas.

LCLUC Applications in the Forestry Sector and in Urban Areas

Forests can undergo degradation due to disturbance from fires, insect infestation, diseases, or extreme weather events. Thus, developing tools to detect forest disturbance from satellite-data is one of the important focus area in forestry research. For example, on a global scale, the time-series vegetation change tracker algorithm can be used effectively to detect forest disturbance using Landsat data. Annual forest disturbance records for the U.S. and Canada are available.[14] As a part of ESA's Fire Climate Change Initiative (Fire-CCI) project, burnt areas are being mapped during the period 2001-2017 on a global scale using MODIS 250-m (~820-ft) data.

In the Philippines, the National Mapping and Resource Information Authority (NAMRIA) is responsible for forest mapping and monitoring. NAMRIA initiated national land scale cover mapping using digital classification of Landsat data from 2003, 2010, and 2015; mapping efforts are ongoing for 2017–2020. For the 2017–2020 mapping, Sentinel data in addition to Landsat 7 and 8 data will be used. Forest cover classification using lidar data was also attempted for 2012-2017 as part of a national mapping program in the Philippines.

In India, major drivers of LCLUC include urbanization and population growth. Extreme climate events such as floods and droughts also impact LCLUC. Specific to Andhra Pradesh State, agricultural lands are being converted to Eucalyptus, Leucaena, and Casuarina plantations, as they need less human activity than other crops for their growth.

In Myanmar, forest-type mapping from 2016, including identifying drivers of deforestation, is being led by the Smithsonian Conservation Biology Institution, with the help of the Forestry Department, One-Map Myanmar Project Team, Yangon Institute of Technology, and local nongovernmental organizations. UMCP researchers are studying the role of LCLUC in malaria transmission under changing socioeconomic and climate conditions in Myanmar with fine-resolution Worldview[15] data for land-cover mapping.

In Nepal, the deforestation rate is decreasing due to community forestry programs and privately managed agroforestry. In Indonesia, digital classification methods using Landsat and lidar data including automated digital preprocessing, are being used for forest classification as a part of a collaborative project.

In the Mekong Delta, rice-paddy cultivation, shrimp farming, and urbanization are destroying the mangrove ecosystems. Researchers from Michigan State University are studying LCLUC-related *water-energy food (WEF) nexus*[16] and challenges in the upper Mekong Basin. Preliminary results suggest that construction of new dams can affect the mainstream flows in the Mekong.

In Vientiane, Laos, urbanization is occurring rapidly. An operational LCLUC mapping and monitoring program at the country level is a high priority. In Malaysia, greenspace in several cities is fast disappearing; whereas in Kaula Lumpur an increase in greenspace has been observed since 2010.

Conclusion

The SARI meeting in the Philippines served as a forum for the exchange of ideas and information across a diverse range of SARI researchers. Regional researchers emphasized the need to continue SARI meeting and training activities[17] for the benefit of the LCLUC community, not only to enhance regional science, but also to address policy-relevant LCLUC issues in the region.

Three publications are planned to record and describe discussions at the meeting. These include:

- A special issue of *Remote Sensing* (*https://www.mdpi.com/journal/remotesensing/special_issues/lclu_sasia*);
- a special issue of *Environmental Pollution* (*https://www. journals.elsevier.com/environmental-pollution/call-for-papers/call-for-papers-on-greenhouse-gases-shortlived-climate-poll*); and
- a two-volume book set focusing on biomass burning published by CRC Press, Taylor & Francis Group.

Interested authors should contact **Krishna Vadrevu** (Krishna.p.vadrevu@nasa.gov) for details on article submissions.

[14] See *https://daac.ornl.gov/NACP/guides/NAFD-NEX_Forest_Disturbance.html*.

[15] Worldview is a tool developed by the Earth Observing System Data and Information System (EOSDIS) that allows users to interactively browse global satellite imagery—within hours of it being acquired. Learn more at *https://worldview.earthdata.nasa.gov*. The complete record of MODIS imagery is now available in Worldview. To learn more see "NASA's Worldview Places Nearly 20 Years of Daily Global MODIS Imagery at Your Fingertips" in the July–August 2018 issue of *The Earth Observer* [**Volume 30**, **Issue 4**, pp 4-8—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/July-August%20 2018%20Color%20508.pdf#page=4*].

[16] *WEF nexus* refers to the places these three related sectors—water security, energy security, and food security—converge. The three are inextricably linked and the actions in one area more often than not have impacts on one or both of the other areas.

[17] After the meeting, 130 early-career scientists and students from the SARI countries participated in a three-day, hands-on training, focused on the use of remote sensing and geospatial technologies for LCLUC applications. Specific topics included, Introduction to Remote Sensing, Multi-Temporal Analysis of Satellite Images, Modeling of LCLUC, Forest Disturbance Mapping, SAR Remote Sensing Data and Applications, Machine Learning Tools, and Cloud Computing Using Google Earth Engine.

Summary of 2018 ASTER Science Team Meeting

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Introduction and Overview

The forty-ninth U.S.–Japan meeting of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Science Team was held at Japan Space System's offices in Tokyo, Japan, June 4-6, 2018. The meeting attracted over 40 participants and offered 5 working-group (WG) sessions. From the U.S., participants were from NASA's Goddard Space Flight Center (GSFC), NASA/Jet Propulsion Laboratory (JPL), University of Pittsburgh (UP), University of Arizona (UA), University of Washington (UW), University of Hawaii (UH), and U.S. Geological Survey (USGS). From Japan, participants were from Japan Space Systems (JSS), Ibaraki University (IU), Nagoya University (NU), University of Tokyo (UT), National Institute of Advanced Industrial Science and Technology (AIST), Geological Survey of Japan (GSJ), Sensor Information Laboratory Corp. (SILC), National Institute for Environmental Studies (NIES), and Japan Aerospace Exploration Agency (JAXA). The main goals of the meeting were to:

- Discuss the status of the ASTER instrument and Terra spacecraft;
- review the August 2017 Terra spacecraft's Lunar Deep Space calibration maneuver;
- discuss the release of Version 3 of the Global Digital Elevation Model (GDEM3); and
- provide updates on image acquisition scheduling for the following year.

Opening Plenary Session

The meeting opened with greetings from the Japan and U.S. Team Leaders, **Y. Yamaguchi** [NU] and **M. Abrams** [JPL].

M. Abrams reported on the start of negotiations between Japan's Ministry of Economy, Trade, and Industry (METI) and NASA for the continuation of the ASTER project beyond October 2019, when the current agreement expires. NASA has recently announced four new members of the U.S. ASTER Science Team: V. Realmuto [JPL]; D. Pieri [JPL]; M. Ramsey [UP]; and R. Wright [UH]. All of the new Team members are volcanologists. Abrams also highlighted ASTER's participation in the Hawaii volcano campaign,[1] where NASA brought its ER-2 aircraft, equipped with four imaging sensors.[2]

M. Abrams then gave a report as proxy for **W. Turner** [NASA HQ—*Program Scientist for Biological Diversity* and *Program Manager for Ecological Forecasting*] in which he described developments from the Second (2017-2027) Earth Science Decadal Survey.[3] In early 2019, NASA will decide which of its field centers

[1] This campaign also involved a study of Hawaii's coral reefs. The campaign provided precursor data for NASA's proposed Hyperspectral Infrared Imager (HyspIRI) satellite mission concept to study Earth ecosystems and natural hazards such as volcanoes, wildfires, and drought.

[2] These instruments include the: Advanced Visible–Infrared Imaging Spectrometer (AVIRIS); MODIS–ASTER Airborne Simulator (MASTER); Hyperspectral Thermal Emission Spectrometer (HyTES); and Portable Remote Imaging Spectrometer (PRISM).

[3] The full text of the Second (2017–2027) Earth Science Decadal Survey, *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observing from Space* (2018), can be downloaded from *https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth*.

Attendees at the 2018 ASTER Science Team Meeting held in Tokyo, Japan. **Photo credit**: T. Tachikawa/JSS will be responsible for the Surface Biology and Geology (SBG) mission/observing system.[4] SBG builds on the demonstrated capabilities of ASTER's multispectral thermal infrared (TIR) channels, and the ten-year Hyperspectral Infrared Imager (HyspIRI) mission study.[5]

J. Hendrickson [GSFC] then discussed the status of the Terra spacecraft, on which all systems continue to operate nominally. There is enough fuel to maintain Mean Local Time (MLT) of the orbit equatorial crossing and the orbit altitude until 2022. After exiting the Morning Constellation orbit at that time, Terra is expected to continue operating at a lower altitude and drifting MLT until 2026. Data capture continues at nearly 100%.

T. Maiersperger [USGS] discussed NASA's Land Processes Distributed Active Archive Center's (LPDAAC) plan to release GDEM V3. Higher-level data processing software will soon offer users the choice of output created from either the earlier Level 1B input, or the newer Level 1T (geocoded and orthorectified) input. He also noted that the GDEM continues to be the most frequently requested ASTER product.

Working Group Meeting Discussions

The bulk of the meeting was dedicated to deliberations of various working groups. Each subsection below summarizes the purpose of each working group, and then gives highlights from the discussion.

Radiometric Calibration Working Group

The Radiometric Calibration WG is responsible for monitoring the ASTER instruments to understand and characterize their responses to scenes being observed. The WG noted that the instrument response is changing smoothly with time. They determined updated calibration coefficients to maintain calibration of the data. Data from the onboard visible/near infrared (VNIR) calibration lamps and onboard TIR blackbody are combined with *in situ* field validation campaigns to monitor the instruments' performances. The individual reports in this subsection delve into the details of specific calibration activities connected to Terra in general, and ASTER in particular.[6]

M. Kikuchi [JSS] reported that Terra's August 2017 Deep Space Lunar Calibration Maneuver[7] (illustrated in **Figure 1**) has been helpful for ASTER image processing. Since the maneuver was completed, there has been an improvement of the sensitivity correction parameter (verified using both onboard and vicarious calibrations), making it possible to continue to produce high quality products. Based on these results, scientists hope to create a standard database on optical sensors calibration and verification that can be used to and contribute to the validation of data obtained by small satellites, or other instruments that do not have onboard calibration capabilities.

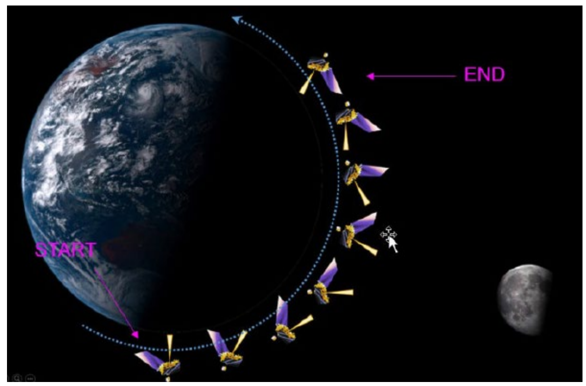

Figure 1. This diagram shows the progression of Terra's Deep Space Lunar Calibration Maneuver executed in August 2017, when Terra did a 360° pitch-over maneuver (essentially, a "backflip") to observe the moon. **Image credit:** T. Kouyama

T. Kouyama [JSS] presented his analysis of the August 2017 Deep Space Lunar Calibration Maneuver. His analysis confirms the responsivity change of the VNIR channels, and validates the current calibration method for Bands 1 and 2, which is based on a combination of vicarious calibration, cross-comparison with other instruments, and interband comparisons. Calibration of Band 3N is based on onboard calibration lamps, which are known to have degraded.

S. Tsuchida [AIST] discussed vicarious calibration of the ASTER instrument using results from field campaigns at Railroad Valley, NV. The observed trend in VNIR radiometric calibration coefficients emerging from such vicarious calibration experiments appears

[4] In a departure from its predecessor, the Second Earth Science Decadal survey emphasizes types of observations as opposed to specific missions allowing for more flexibility in implementing the recommendations of the survey. It does however identity five *Designated Observables* for mandatory acquisition: Aerosols; Clouds, Convection, and Precipitation; Mass Change; Surface Biology and Geology; and Surface Deformation and Change.

[5] HyspIRI was identified as a Tier 2 priority mission in the First Earth Science Decadal Survey, which can be downloaded without cost from *https://www.nap.edu/catalog/11820/earth-science-and-applications-from-space-national-imperatives-for-the*.

[6] This article discusses two common techniques used for on-orbit calibration. *Vicarious calibration* is when a sensor makes use of "invariant" natural targets on Earth (e.g., deserts, forests, snow covered areas) for post-launch assessments of stability; *onboard calibration* makes uses of lamps and reference standards onboard the spacecraft itself.

[7] To learn more about this maneuver, see "Terra Flips for Science" in the September–October 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 5**, pp. 18-19]—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/Sept_Oct_%202017_color.pdf#page=18*.

stable. Intercomparisons with Landsat and MODIS[8] were performed based on synchronous data.

H. Tonooka [IU] discussed the results of field experiments carried out at Alkali Lake, NV, and Lake Kasumigaura, Japan. The results indicate that the onboard blackbody calibrator for the TIR channels is keeping the design accuracy of 1 K in the temperature range of 0 to 36 °C (32 to 97 °F). Two additional campaigns in Nevada and two campaigns at Lake Kasumigaura are planned for the coming year. The possibility of a campaign at a frozen lake (location to be determined) is also being investigated.

S. Hook [JPL] discussed the Lake Tahoe and Salton Sea (California) automated validation sites used to assess ASTER's radiometric accuracy. The Lake Tahoe site was established in 1999 and the Salton Sea site in 2008. Both the daytime and nighttime validations have slightly negative bias. Results indicate ASTER meets preflight specification and has operated within preflight specification for the duration of the Terra mission. Results obtained during 2017–2018 show that ASTER TIR performance was within range of recent years–i.e., it shows the same general pattern during 2017–2018 as it did the previous couple of years.

K. Thome [GSFC] described the Radiometric Calibration Network (RadCalNet),[9] which consists of multiple automated *in situ* measurement sites operated independently but using the same methodology and processing chain with known and documented uncertainties. RadCalNet products include top-of-atmosphere reflectance. RadCalNet sites include Railroad Valley Playa, NV (RadCaTS), and La Crau, France (Gobabeb). Data will be freely available to anyone that registers at the RadCalNet portal. Preliminary analysis shows good agreement between ASTER L1T data and RadCalNet observations obtained at both Railroad Valley and La Crau. More data from operational sites need to be evaluated.

[8] MODIS stands for Moderate Resolution Imaging Spectroradiometer, which flies on NASA's Terra and Aqua platforms.
[9] Learn more at *https://www.radcalnet.org/#*.

Applications Working Group

The Applications WG provides a platform for team members to present and discuss their science research activities using ASTER data. Its sessions usually span two days of the meetings. The majority of work is being done in the disciplines of geology, oceanography, and ecology.

K. Hirose [JSS] reported on a study to monitor coastal erosion on the island of Java, Indonesia. Using a time history of ASTER and Landsat data extending back more than 20 years, Hirose found that coastal erosion had two main causes: subsidence leading to seawater incursion; and mangrove deforestation due to conversion to aquaculture, rice cultivation, development of oil palm plantations, and urban development, all of which cause destabilization of the coastal areas.

R. Wright [UH] presented his work to integrate ASTER with MODIS/VIIRS[10] for quantifying volcanic unrest. He illustrated an improved hot spot detection algorithm for MODVOLC.[11] Using Google Earth Engine, Wright will gap-fill the global high-temporal-resolution MODIS/VIIRS record with high-spatial- but low-temporal-resolution ASTER and Landsat data for low-intensity activity—as illustrated in **Figure 2**.[12] Statistical analysis of the 20-year record will improve detection of eruption precursors as a function of the idiosyncratic behavior of individual volcanoes.

M. Abrams spoke on behalf of **J. Kargel** [UA], whose presentation highlighted glaciological applications of ASTER data. In the previous few months, many articles, making major use of ASTER data, appeared in

[10] VIIRS stands for Visible Infrared Imaging Radiometer Suite, which flies on the Suomi National Polar-orbiting Partnership (NPP) mission and on the Joint Polar Satellite System-1, which is now referred to as NOAA-20.
[11] MODVOLC is a University of Hawaii operational program to provide near-real-time satellite monitoring of global volcanism using MODIS. For more information, visit *http://modis.higp.hawaii.edu*.
[12] This figure has been published in *Remote Sensing of Environment*, online at *https://www.higp.hawaii.edu/~wright/rse131.pdf*.

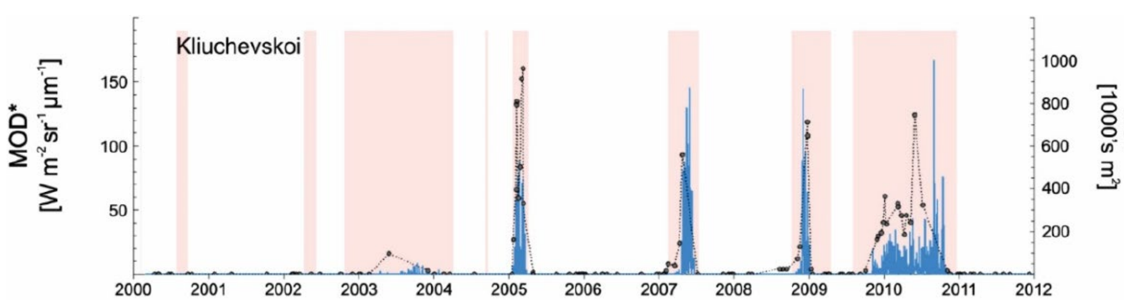

Figure 2. The blue curve shows the spectral radiances emitted from the lava flows and the summit crater of Kliuchevskoi Volcano, Kamchatka, Russia, for the period 2000-2012, as recorded by low-spatial-resolution [1-km (~0.6-mi)] MODIS data (y-axis labeled MOD on left side). Black dots show the same activity as recorded by the higher-resolution [(90-m (~295-ft)] ASTER sensor (y-axis labeled AST on right side; units are thousands of square meters of elevated temperature), using a metric that reconciles the different wavelengths and spatial resolutions of these two sensors, allowing them to be used side-by-side to quantify volcanic activity at high- and low-spatial resolution. **Image credit**: Murphy *et al.*

several journals (e.g., *The Cryosphere*, *Nature Geoscience*, and *Water*). Scene digital elevation models (DEMs) were of critical importance to determining glacier volumes as a function of time. ASTER has offered this unique capability for nearly 20 years. The article that was published in *The Cryosphere* made use of over 50,000 ASTER scene-based DEMs to calculate the mass balance of glaciers in the high mountains of Asia.

Y. Ninomiya [GSJ] discussed his method for mapping mineralogical indices using ASTER TIR data at both global and regional and local scales. He created mineralogical indices to detect the occurrence of carbonates, quartz, and mafic minerals.

Operations and Mission Planning Working Group

The Operations and Mission Planning WG oversees all scheduling of ASTER instruments. Because ASTER acquires data only on demand, a complex scheduling algorithm has been developed to assemble daily schedules for which scenes will be acquired. Various mapping programs run simultaneously, such as the global mapping program that operates in the background when no higher-priority acquisitions are scheduled.

M. Fujita [JSS] presented updates of the observation status for ASTER's mapping programs and data acquisition. The Global Mapping-7 program has successfully acquired about 71% of the programmed scenes with 20% or less cloud cover. The group recommended starting Global Mapping-8 in October 2018. The currently running Nighttime TIR Global Mapping program has achieved a 92% success rate. Based on recommendations from the Temperature-Emissivity Separation Working Group (discussions summarized below), a new mapping will start in June 2018.[13] The Underserved Area program (an effort to acquire images over persistently cloudy areas) will be restarted sometime in the summer of 2018. The Glacier Monitoring Program will continue for at least one more year, but the program will be evaluated to assess its viability beyond that. The Volcano Monitoring Program (which provides frequent day and night coverage of 1500 active volcanoes) will continue for the next few years. The Remote Island Program (which obtains single scenes over isolated mid-ocean targets) will restart in the summer of 2018. Fujita also summarized those observations that fall under the rubric of urgent observations (which include field campaigns, volcano monitoring, and natural hazards). About 2% of the requests for Urgent Observations failed to be processed. Fujita went through the details of each individual failed request. In general, the failures occurred because the requests were received after the allowed scheduling window had closed.

H. Tonooka [IU] provided an update of the ASTER cloud reassessment. The MODIS35 cloud assessment product had been updated from Version 6.0 to 6.1. The ASTER cloud assessment relies on this product, so Tonooka has updated the ASTER assessment as of January 2018. His evaluation indicated that 1% of ASTER scenes show a greater than 25% discrepancy in cloud coverage between the old product and the new one.

Level 1-DEM Working Group

The Level 1-DEM WG is responsible for monitoring the performance of the Level 1 processing software, monitoring the geometric performance of the VNIR and TIR instruments, and overseeing the GDEM product.

T. Maiersperger [USGS] discussed the geolocation error distribution of the Level 1T product, using the Landsat assessment system to conduct his analysis. Geometric accuracy was found to be consistent over time, with no anomalous behavior noted in the data acquired during the past year. As reported at previous ASTER Science Team Meetings, the scenes with the largest errors are in the cloudy tropics.

M. Abrams provided an overview of the soon-to-be-released ASTER Water Body Dataset (ASTWBD). This is a unique, global, raster data set that identifies water-bodies and separates them into lakes, rivers, and ocean categories. In addition, elevations are provided for each water body, including decreasing elevations for rivers from their start to their end in lakes or ocean. He noted that a user guide has been completed, and that the ASTWBD will be released and distributed jointly by the LPDAAC and JSS at the same time as GDEM V3 is released.

M. Abrams went on to provide some details about GDEM V3. This is the final update to the GDEM that the ASTER Science Team plans to make; it was created by editing of GDEM3 acquired from SILC in Japan. Robert Crippen [JPL] reprocessed GDEM3 to remove remaining artifacts, and to fill voids with other data sets. Residual problems where clouds occurred, where errors introduced by filling voids with a low-quality DEM, and from other anomalies have been identified and corrected. The result is a virtually error-free dataset. A draft user guide was shown and distributed to the Japan ASTER Science Team for editing. THE GDEM V3 will be jointly released and distributed by JSS and LPDAAC in the summer of 2018.

Temperature/Emissivity Separation Working Group

The Temperature-Emissivity Separation (TES) WG is responsible for monitoring and maintaining the algorithms that produce the calibrated temperature and

[13] **UPDATE**: The new mapping began in June 2018 as planned.

emissivity ASTER products from the Level 1 TIR data. The group monitors the acquisition program that obtains global coverage of Earth's entire land surface. A nighttime global time-series is obtained by repeating the acquisition scheduling on a regular basis (i.e., restarting every few years).

H. Tonooka presented an update on the Satellite-based Lake and Reservoir Temperature Database in Japan (SatLARTD-J). The database now covers 1005 inland bodies of water in Japan, and uses ASTER TIR data as inputs. The radiance data are recalibrated, corrected for stray light, corrected for atmospheric water vapor, and input into the TES algorithm; ASTER-derived water temperatures are the output. Temperature retrieval errors are generally about 1 K.

H. Tonooka also discussed his evaluation of MODIS thermal anomaly products using ASTER images. He investigated the influence of the subpixel position of a hotspot in the MODIS product using MODIS images accurately simulated from simultaneously acquired ASTER images. He showed that a thermal anomaly could not be detected by MODIS if it was located at the boundary between pixels.

S. Hook discussed validation of ASTER TES algorithm applied to data from the Lake Tahoe and Salton Sea calibration sites in Nevada. He compared the ASTER standard temperature product with temperature measurements made in situ with highly accurate radiometers, and used a radiative transfer code to propagate the surface radiance through the atmosphere and to the satellite. The results agree to well within algorithm requirements of 1 K.

The TES Working Group has evaluated the success of the Thermal Global Mapping (TGM) acquisition program. Version 9 of the TGM (TGM-9 has achieved over 92% success. The group recommended that TGM-10 should be started as soon as possible, with the same priorities and areas as TGM-9.

Closing Plenary Session: Meeting Summary

The chairpersons of each of the WG presented summaries of presentations and subsequent discussions for each of their sessions, which led to further discussion or relevant information by the team as a whole. The overall "sense of the Team" is that the Terra platform in general, and the ASTER instruments specifically, are performing nominally—with no significant change since the preceding 2017 team meeting. Continuing discussions about the August 2017 Deep Space Lunar Calibration Maneuver verified that the maneuver was completely successful; results will be incorporated in the next update of radiometric calibration coefficients. The GDEM V3 will be released in the summer of 2018, pending final correction of the few remaining artifacts. The next meeting will be held June 10-12, 2019, at the same venue in Tokyo. ■

Acknowledgment

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NASA Assists in Efforts to Contain California Wildfires

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EDITOR'S 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.

An effort by multiple NASA centers to assist with suppressing California wildfires included capturing satellite data of the smoke plumes and aircraft flights over burned areas to collect information for recovery planning.

The California Air National Guard asked the NASA Earth Science Disasters Program for support with the wildfires that have destroyed more than 410,000 acres [~1659 km^2], and 11 disaster program members arrived July 29, 2018. The NASA contingent coordinates NASA resources to provide detailed information, maps, and images.

"Our goal is to provide the best support possible to our long-standing partners in the state of California," said **Carver Struve** [NASA Headquarters—*Emergency Management Co-Lead*].

From NASA's Armstrong Flight Research Center in California, a high-altitude aircraft and two pilots assisted in two separate efforts to collect infrared imagery of California's raging wildfires and the damage they caused. The most intense of those wildfires was in the Mendocino Complex—which became the largest wildfire in California history. The data collected through the two efforts were used to fight the fires, to provide data to recover from them, and to study future blazes.

NASA's ER-2 flew a NASA thermal imaging camera—image from camera shown in the **Figure**—to assess some of the fire damage to help officials estimate the resources needed to recover from the fire, as well as identify some potential dangers from challenges such as mudslides this winter, said **Jeffrey Myers** [NASA's Ames Research Center (ARC)—*Manager of the Airborne Sensor Facility*]. The facility is managed by Universities Space Research Association (USRA).

The ER-2 was conducting a mission that uses airborne sensors to simulate future satellite data products by flying over large sections of California as part of a long-term study, Myers explained. On the August 9 flight, the mission team tested a key component on the aircraft referred to as the Moderate Resolution Imaging Spectroradiometer (MODIS)-Advanced Spaceborne

Figure. The Mendocino Complex Fire is the largest wildfire in California history with well over 350,000 acres (~1214 km^2) burned. This image was captured on August 9, 2018, by an instrument installed aboard a NASA research aircraft that flew over both fires making up the complex in the area around Clear Lake (the central, black feature) in northern California. Active fire zones are seen in yellow, with warm, burned areas in orange. Unburned vegetation appears in blue and green. The flames of small, active fires can be seen at the leading edges of the fire perimeter. **Image credit:** NASA/USRA

Thermal Emission and Reflection Radiometer (ASTER) Simulator, or MASTER.[1] That instrument will be used for an intensive study of North American fires with the National Oceanic and Atmospheric Administration called the Fire Influence on Regional to Global Environments and Air Quality (FIREX-AQ).

"The MASTER sensor is operated in support of principal investigators from NASA's Goddard Space Flight Center in Maryland and the NASA/Jet Propulsion Laboratory in Pasadena," Myers said. "It is used for Earth science research in conjunction with the NASA MODIS and ASTER satellite instruments."

With as many as 18 wildfires burning in the state, **James Nelson** [*NASA Research Pilot*] was tasked with flying a 3.6-hour mission in the ER-2 at 65,000 ft (19,812 m) on August 9.

"The two fires near Yosemite could clearly be seen from my altitude, but the Mendocino fire was obscured by smoke," Nelson said. "However, our instruments are multispectral and can see through much of the smoke in the infrared bands and we were able to collect data on all the fires."

The ER-2 aircraft flew a fire mission during the Thomas blaze in Ventura County, CA, in December 2017.

Myers explained the mission focus.

"We were looking at the infrared data over the active burn area to evaluate the instrument performance," he explained. "We have colleagues in the U.S. Forest Service in Salt Lake City who wanted the data. They have an infrared mapping aircraft covering those fires, but they needed the information for their burned area emergency response plan. They have 48 hours from when the fire is declared contained to deliver a draft response plan about how to control erosion and begin revegetation. They also will look at severity of burn for areas that are most susceptible to mudslides."

In another area of California, **Scott Howe** [NASA Armstrong Flight Research Center—*Pilot*], who was serving as a part-time member of the California Air National Guard, was on duty the week of August 6. He assisted with the blazes by piloting the guard's MQ-9 remotely piloted aircraft during launch and landing of aircraft used to monitor raging wildfires.

Howe explained the role of the California Air National Guard.

"The aircraft shows Cal Fire (the state's arm of the U.S. Department of Forestry and Fire Protection) where the biggest threats to people and property are located, the hottest areas, and those parts of the fire that are most rapidly growing so they can deploy resources."

Howe was chosen for that role the week of August 6 because of his familiarity with the MQ-9. He was one of the pilots of NASA's Ikhana aircraft, a civilian variant of the MQ-9 based at Armstrong until the aircraft was recently reassigned. One of the Ikhana's missions, while based at Armstrong, was to validate technologies that could be used to monitor and map fires as they were happening during the Western States Fire Missions in 2006 and 2007.

The hours leading up to his first shift on August 6 were eventful.

"The aircraft was coming back on my first night and the crew discovered a new fire between the Carr fire near Redding and the Mendocino fire," he said. "The blaze that the crew sited became known as the Eel fire. They were the first to spot it and report it to the Cal Fire commander."

Howe watched the infrared imaging on large screen monitors in the operations center, which is like a NASA control room, and saw how the fires were being mapped out and communicated to Cal Fire's command center.

"You can clearly see burn areas have a residual heat, even in the middle of the night, and the bright leading edge, like a string of jewels," Howe said. "At the hottest part, you can see the flames licking off the top of it. It's pretty intense." ■

[1] MODIS flies on NASA's Terra and Aqua platforms; ASTER flies on Terra.

Expedition Probes Ocean's Smallest Organisms for Climate Answers

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EDITOR'S 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.

Satellite images of phytoplankton blooms on the surface of the ocean often dazzle with their diverse colors, shades, and shapes. But phytoplankton are more than just nature's watercolors: They play a key role in Earth's climate by removing heat-trapping carbon dioxide from the atmosphere through photosynthesis.

Yet obtaining a detailed account of what becomes of that carbon—i.e., how much of it goes where within the Earth and for how long—has beset scientists for decades. While NASA's Earth-observing satellites can detect the proliferation and location of these organisms, the precise implications of their life and death cycles on the climate are still unknown.

To answer those questions, in August a large multidisciplinary team of scientists sailed 200 mi (~320 km) west from Seattle into the northeastern Pacific Ocean with advanced underwater robotics and other instruments on a month-long campaign to investigate the secret lives of these plantlike organisms and the animals that eat them.

NASA and the National Science Foundation are funding the Export Processes in the Ocean from Remote Sensing (EXPORTS) oceanographic campaign. With more than 100 scientists and crew from nearly 30 research institutions, EXPORTS is the first coordinated multidisciplinary science campaign of its kind to study the pathways, fates, and carbon cycle impacts of microscopic and other plankton using two research vessels, a range of underwater robotic platforms, and satellite imagery. The team will work from the research vessels (R/V) *Roger Revelle* and *Sally Ride,* operated by the Scripps Institution of Oceanography, University of California, San Diego.

"The continued exploration of the ocean, its ecosystems, and their controls on the carbon cycle as observed with advanced technologies by EXPORTS will provide unprecedented views of Earth's unseen world," said **Paula Bontempi** [NASA Headquarters—*Program Manager for NASA's Ocean Biology and Biogeochemistry Research Program* and *EXPORTS Program Scientist*]. "The science questions the team is tackling really push the frontier of what NASA can do in both remote and *in situ* optical ocean research. NASA's goal is to link the biological and biogeochemical ocean processes to information from planned ocean-observing satellite missions, thus extrapolating the results from this mission to global scales."

The research vessels Sally Ride [*left*] and Roger Revelle [*right*] carry more than 100 scientists from more than 20 different research institutions, as well as lab gear and underwater robotic explorers to support EXPORTS. **Photo credit:** NASA's Goddard Space Flight Center/ Michael Starobin

The challenge that EXPORTS addresses requires an extremely multidisciplinary team of experts. "I am in awe that we've been able to bring together a team of true leaders in their individual fields with the single goal of understanding the interactions among life in the sea and the ocean's carbon cycle," said **David Siege** [University of California, Santa Barbara—*Professor of Marine Science and EXPORTS Science Lead*]. "The team has an unprecedented diversity of expertise, including physicists, ecologists, geochemists, numerical modelers, and genomics, robotics, and remote-sensing scientists."

The word *phytoplankton* comes from the Greek meaning "plant drifters"; phytoplankton harness the Sun's energy to transform dissolved inorganic carbon in the ocean into organic carbon—creating carbohydrates and cellular material for nourishment and reproduction—and their movement is largely dictated by the ocean's physics, including currents. These organisms are microscopic, mostly single-celled, and multiply exponentially, doubling their number on average every day.

Their abundance and high productivity make phytoplankton an ideal food source for small animals called *zooplankton*, which means "animal drifters" in Greek. "If you have a million phytoplankton and zooplankton eat 500,000 of them, the phytoplankton can quickly bounce back to a million within one day," said **Tatiana Rynearson** [The University of Rhode Island—*Oceanographer and EXPORTS Team Member*]. "Phytoplankton provide energy for the whole ecosystem because they're able to replenish their populations rapidly."

Like phytoplankton, zooplankton are diverse in species. Some are single-celled and microscopic (microzooplankton), while others, such as the shrimp-like krill and jellyfish, are plainly visible to the naked eye. Various species live near the ocean's surface all their lives, while others spend their days in the so-called *twilight zone,* from 200 to 1000 m (650 to 3300 ft) below, where there is little or no sunlight. But at night some zooplankton species, such as copepods, which are small crustaceans, make a mass migration to the surface—the largest such journey by number of organisms on Earth—to feed on phytoplankton and microzooplankton, and then retreat back to the depths at sunrise.

Further up the food chain, a variety of larger animals, such as fish—including the giant of the sea, the whale shark—and baleen whales such as the blue whale—the largest animal on Earth—feed on zooplankton, incorporating that organic carbon into their bodies.

Much of the organic carbon consumed by the phytoplankton, zooplankton, and larger marine predators returns to the atmosphere on short timescales. This happens when they decompose and through respiration along this food chain, from the larger animals and the zooplankton to the bacteria that feed on these animals' feces and decomposing bodies. But some of the organic matter from feces and decomposed bodies sinks into the twilight zone and is sequestered on longer timescales.

"It's a tiny fraction, a fraction of a percent of biomass that makes it deeper down in the ocean where the water stays away from the atmosphere for a long time, from decades to thousands of years," said **Heidi Sosik** [Woods Hole Oceanographic Institution—*Senior Scientist and EXPORTS Team Member*]. "We have pretty good information that tells us these processes are happening, but we have much less information to help us to quantitatively assess their impact on things like carbon cycling and, ultimately, Earth's climate."

One objective of the campaign is to improve understanding of plankton through genetics. Rynearson and others will be involved in identifying various phytoplankton and zooplankton species by their DNA and determining which species are at the surface, which are sinking, and which are living in the deep ocean. Studying their genetic makeup will provide insights into their metabolism, which will be analyzed alongside *in situ* measurements of photosynthesis and respiration.

"Essentially, we're trying to pick apart who's there and what they're doing and how much carbon is cycling through these different species," Rynearson said. The genetic data will be linked to optical measurements, conducted as part of the *in situ* work, to help build optical proxies of critical ocean ecosystem and biogeochemical properties. Once these optical ocean proxies are created, scientists will further define and refine approaches to measure ocean ecosystem variables remotely, ultimately linking carbon export processes to satellite measurements.

Deborah Steinberg [Virginia Institute of Marine Science—*Professor of Marine Science*] is co-chief scientist on the R/V Revelle and is studying zooplankton populations. Using a finely meshed, electronically controlled plankton net, Steinberg and her team will be sampling water at different depths, from the surface to 1000 m (3200 ft). They will be counting the abundance of various zooplankton populations at the different depths and bringing samples back on the ship to observe how much feces they produce. Probes on the ship will also measure how much oxygen they're using. "That will give us a good idea of their metabolism and how much each species is recycling or exporting the organic matter that they're eating," she said.

Meanwhile, Sosik and her team will be among the EXPORTS team members looking at the impact of phytoplankton species on the optical properties of the ocean's surface—how they absorb and scatter sunlight—which is fundamental to discerning the signals that satellites retrieve from space. "Combined with data from EXPORTS and other *in situ* seaborne campaigns that feed into models," she said, "satellite data will help us make more sophisticated and refined inferences about what might be happening deeper in the ocean and what the impacts on the carbon cycle might be." ■

NASA Investment in Cholera Forecasts Helps Save Lives in Yemen

Jay Levine, NASA's Armstrong Flight Research Center, jay.levine-1@nasa.gov

EDITOR'S 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.

For the first time ever, measurements from NASA Earth-observing research satellites are being used to help combat a potential outbreak of life-threatening cholera. Humanitarian teams in Yemen are targeting areas identified by a NASA-supported project that precisely forecasts high-risk regions based on environmental conditions observed from space.

"By joining up international expertise with those working on the ground, we have for the very first time used these sophisticated predictions to help save lives and prevent needless suffering for thousands of Yemenis," said **Charlotte Watts** [U.K.'s Department for International Development—*Chief Scientist*].

Cholera is a disease caused by consuming food or water contaminated with a bacterium called *Vibrio cholerae*. The disease affects millions of people every year, resulting in severe diarrhea and even death. It remains a major threat to global health, especially in developing countries, such as Yemen, where access to clean water is limited.

Starting this spring, the British government and international aid groups in Yemen began using these new cholera forecasts to target their work in reducing cholera risk. That work includes promoting good hygiene to prevent the spread of the waterborne disease and distributing hygiene and cholera treatment kits. The results to date suggest the forecast model has the potential to fundamentally change how the international community addresses cholera.

The research on forecasting cholera outbreaks has been funded by NASA's Applied Sciences Program, and is being led by **Antar Jutla** [West Virginia University—*Hydrologist and Civil Engineer*], along with **Rita Colwell** [University of Maryland, College Park—*Microbiologist*] and **Anwar Huq** [University of Maryland, College Park—*Microbiologist*].

The NASA forecast tool divides the entire country of Yemen into regions about the size of a typical U.S. county, and predicts the risk of cholera outbreaks in each region. To calculate the likelihood of an outbreak, the science team runs a computer model that combines satellite observations of environmental conditions that affect the cholera bacteria with information on sanitation and clean water infrastructure.

The forecast tool analyzes a variety of NASA satellite observations, including precipitation data from the Global Precipitation Measurement (GPM) mission, air and ocean temperatures from the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments on NASA's Terra and Aqua satellites, as well as measurements of phytoplankton concentrations in nearby coastal ocean areas.

In 2017, the model achieved 92% accuracy in predicting the regions where cholera was most likely to occur and spread in Yemen that year, even identifying inland areas that are not usually susceptible to the disease but suffered outbreaks—see **Figure**. The Yemen cholera outbreak was the world's worst in 2017, with more than 1.1 million suspected cases and more than 2300 deaths, according to the World Health Organization.

"The model has done an excellent job in Yemen detecting triggers of cholera outbreaks," said Jutla, "but there

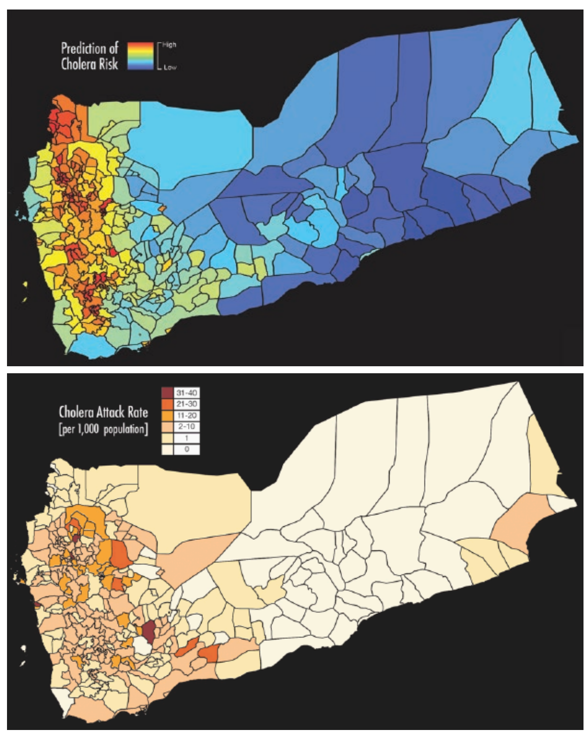


Figure. The *top map* shows the predicted cholera risk based on analysis and satellite data in Yemen, June 2017. Blue color indicates low risk of cholera while red color indicates high risk of cholera. The *bottom map* shows the actual number of cholera cases in June 2017. The red areas represent reported cholera cases. **Image credit:** West Virginia University/Antar Jutla is still a lot of work we need to do to have this forecast model give accurate predictions everywhere."

International humanitarian organizations took notice. This January, **Fergus McBean** [U.K.'s Department for International Development—*Humanitarian Adviser*], read an article about the NASA-funded team's 2017 results and contacted them with an ambitious challenge: to create and implement a cholera forecasting system for Yemen, in only four months.

"It was a race against the start of rainy season," McBean said.

The U.S. researchers began working with U.K. Aid, the U.K. Met Office, and the United Nations Children's Fund (UNICEF) on the innovative approach to using the model to inform cholera risk reduction in Yemen.

In March, one month ahead of the rainy season, the U.K. international development office began using the model's forecasts. Early results show the science team's model predictions, coupled with Met Office weather forecasts, are helping UNICEF and other aid groups target their response to where support is needed most.

"This ground-breaking initiative is a testament to the importance of interdisciplinary and multi-agency efforts to improve disease preparedness and response," said **John Haynes** [NASA Headquarters—*Program Manager for Health and Air Quality Applications*].

McBean believes in this new approach. "We are confident acting on the model's predictions this year. We know that acting early is a more effective way of operating and is likely to result in a much better outcome for people."

Colwell, who compared the 2017 Yemen results to passing the first stage of a three-stage drug trial and discovering the drug is saving the lives of a particular type of patient, said that the science team's next step is to create global risk maps for cholera. In the same way meteorologists issue severe storm warnings, these risk maps and forecasts would allow people to prepare for and prevent disease outbreaks. ■

announcement

Fall AGU Comes to DC—Come EXPLORE NASA Science!

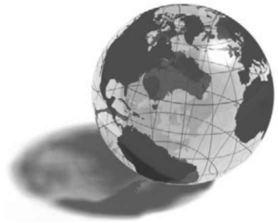
This year's Fall Meeting of the American Geophysical Union will be held in Washington, DC (before returning to its newly renovated "regular" venue in San Francisco, CA in 2019, after a two-year hiatus). For some, this may be a rare opportunity to attend a Fall AGU Meeting closer to home. Make sure your plans include time for one or more visits to the NASA Exhibit. The exhibit hall will open on Monday, December 10, and will continue through Friday, December 14.

The NASA Exhibit will give you a chance to immerse yourself in the Story of NASA Science. You can learn how NASA EXPLOREs and expands the frontiers of science through investigations of Earth science, heliophysics, planetary science, and astrophysics. The focal point of the storytelling experience will be the nine-screen Hyperwall, where scientists will give presentations throughout the week. Other stories will be told at the exhibit via a wide range of science demonstrations, printed material, and tutorials on various data tools and services.

A daily agenda will be posted on the Earth Observing System Project Science Office website—*http://eospso.nasa.gov*—in early December.

We hope to see you in our nation's capital!

A NASA science presentation using the dynamic Hyperwall display during the 2016 AGU Fall Meeting. **Photo credit:** NASA



NASA Earth Science in the News

Samson Reiny, NASA's Goddard Space Flight Center, Earth Science News Team, samson.k.reiny@nasa.gov

EDITOR'S NOTE: This column is intended to provide an overview of NASA Earth Science topics mentioned by online news sources during the past few months. Please note that editorial statements, opinions, or conclusions do not necessarily reflect the positions of NASA. There may be some slight editing in places primarily to match the style used in *The Earth Observer*.

NASA's Earth Science Director to Retire, August 30, *spacenews.com*. The longtime director of NASA's Earth Science Division, who in recent years provided a steadying hand amid budget concerns while seeking to take advantage of new capabilities, will retire from the agency in February 2019. NASA announced August 29, 2018, that **Michael Freilich** will retire in February. The agency plans to start a search for a successor in the fall in order to ensure a smooth transition. "Words are not enough to express my deep appreciation for Mike Freilich's dedication, creativity, and operational vision that has so positively impacted not only Earth science but also the broader NASA research community," said **Thomas Zurbuchen** [NASA HQ—*Associate Administrator for Science*] in a statement about Freilich's retirement. Freilich came to NASA Headquarters after a research career at NASA/Jet Propulsion Laboratory and Oregon State University, where he was a professor and associate dean in the university's College of Oceanic and Atmospheric Sciences. During that time he was a member of research teams for several NASA Earth science missions devoted to studies of ocean surface wind velocity. At NASA, Freilich led several major changes as the division shifted from a handful of large missions to a greater number of smaller missions. That included supporting a new *Venture Class* program of small satellite and airborne projects, as well as utilizing the International Space Station as a platform for Earth science instruments.

***Cholera Outbreak in Yemen Measured by NASA from Space with Its Satellites**, August 28, *greatlakesledger.com*. Measurements from NASA's Earth-observation research satellites are being used, for the first time, to help combat a possible cholera outbreak in Yemen. Humanitarian country teams are focusing on areas identified by a U.S.-funded project that accurately forecasts high-risk regions based on the environmental conditions observed from space by satellites. Funded by NASA's Applied Sciences Program, the research is led by hydrologist and civil engineer **Antar Jutla** [University of West Virginia], along with microbiologists **Rita Colwell** and **Anwar Huq** [both from the University of Maryland]. NASA's forecasting tool divides all of Yemen into regions the size of a typical U.S. county, and predicts the risk of the potential cholera outbreak in each area. To estimate the likelihood of an epidemic, the team of scientists is running a computer model that combines satellite observations of environmental conditions affecting the cholera bacteria with information on sanitation and clean water infrastructure. In 2017, the prediction model achieved 92% accuracy in assessing which regions in Yemen were more exposed to cholera that year, even identifying continental areas that are usually not susceptible to the disease but have experienced outbreaks. The cholera outbreak in Yemen was the worst in the world in 2017, with more than 1.1 million suspected cases and more than 2300 deaths, according to the World Health Organization.

***The Ocean's "Twilight Zone" Is Affecting Earth's Climate**, August 15, *foxnews.com*. It may not be a dimension as vast as space nor as timeless as infinity, but the ocean's "twilight zone" is affecting Earth's climate, due to the heavy presence of phytoplankton in the region. NASA scientists are venturing into the ocean's twilight zone to explore how phytoplankton are affecting Earth's climate. Phytoplankton, which have been described by NASA as "nature's watercolors," remove carbon dioxide (CO_2) from the atmosphere via photosynthesis. Although scientists understand how the carbon is captured, they do not yet understand where it eventually goes, nor how long it stays there, especially when the phytoplankton die or become food for other creatures. A team of over 100 scientists is working to understand where the carbon goes, in a project known as Export Processes in the Ocean from Remote Sensing (EXPORTS). The scientists will use underwater robots, satellite imagery, and two research vessels, as they set sail on a month-long journey 200 miles west of Seattle into the northeastern Pacific Ocean. "The continued exploration of the ocean, its ecosystems, and their controls on the carbon cycle as observed with advanced technologies by EXPORTS will provide unprecedented views of Earth's unseen world," said **Paula Bontempi** [NASA HQ—*EXPORTS Program Scientist*]. Bontempi continued: "The science questions the team is tackling really push the frontier of what NASA can do in both remote and *in situ* optical ocean research. NASA's goal is to link the biological and biogeochemical ocean processes to information from planned ocean-observing satellite missions, thus extrapolating the results from this mission to global scales."

NASA Astronaut's Final Paper Posthumously Tackles Climate's Carbon Cycle, July 17, *laboratoryequipment.com*. NASA astronaut **Piers J. Sellers** was working on advanced models for visualizing and predicting the carbon cycle at a planetary level, when he was diagnosed with stage-4 pancreatic cancer. Sellers worked with his colleagues for nearly another year on the project—and up to six weeks before his death in December 2016.[1] The paper focuses on a 2015 phenomenon, when human carbon emissions leveled off for the first time in documented history, but the CO_2 concentrations in the atmosphere actually accelerated. This occurred during an El Niño weather pattern, and resulted in 30% additional annual growth rate of CO_2. The paper explains how the team used data from the Orbiting Carbon Observatory-2 (which was launched in July 2014) to assess the factors that had created a kind of feedback loop within the cycle, e.g., weather patterns, droughts, and fires. Although 50% of current emissions are offset by the ocean and various land ecosystems, it is still uncertain whether the ocean and key forest ecosystems act as a carbon sink to absorb the carbon, or if they eventually convert to contributors of carbon themselves. The satellite observations demonstrated an ability to produce better models to understand what will happen through the rest of the twenty-first century, but improvements still need to be realized, the authors wrote. The authors concluded that, "Advancing these capabilities requires continued efforts on the development missions, the maturation of algorithms, calibration/validation procedures, and improved inverse and assimilation models, as well as the integration of multiple tracers of both Earth system and anthropogenic processes."

NASA Is Building Models to Predict Mosquito-Borne Illnesses and You Can Help Them Do It, July 6, *houstonchronicle.com*. The 2015 Zika virus outbreak caused panic across the globe. Women who were pregnant or trying to get pregnant were warned against traveling to tropical areas where they could get bitten by carrier mosquitoes. NASA researchers hope to alleviate some of the panic in the future by developing models to predict the next mosquito-borne illness outbreak. And they're asking the public for help in doing this. "We do not have enough information on the geographic distribution of mosquitoes and time-variation in their populations," said **Assaf Anyamba** [NASA's Goddard Space Flight Center (GSFC)—*Research Scientist*]. "If a lot of people participated in this citizen-science initiative worldwide, it would help fill in gaps and that would help our work." About a year ago, the space agency began combining citizen-provided information with Earth satellite observations—such as land surface temperature, humidity, and precipitation—to create an interactive map that will improve prediction models. Early results show that vegetation, humidity, and soil moisture make it easier for mosquitoes to thrive in the summer. To get more accurate data, however, the agency needs more citizen participation. So, officials are asking people all over the world to help. Anyone can download the Globe Observer app (*https://observer.globe.gov*) and collect data this summer using the Mosquito Habitat Mapper tool. That information will then be funneled into a global database for use by scientists. Public health authorities also can access this information to help manage the risk of disease in their communities. "Knowing the mosquito species and their approximate populations at a given time provides useful information on the potential of occurrence of a particular pathogen, or disease transmission," said Anyamba.

[1] Seller's final paper was published posthumously in the *Proceedings of the National Academy of Sciences* (*http://www.pnas.org/content/early/2018/07/05/1716613115*) and dedicated to him by his surviving colleagues, who completed the work.

*See news story in this issue.

Interested in getting your research out to the general public, educators, and the scientific community? Please contact ***Samson Reiny*** *on NASA's Earth Science News Team at samson.k.reiny@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****.*

Earth Science Meeting and Workshop Calendar

NASA Community

October 1-5, 2018
Sounder Science Team Meeting, Greenbelt, MD.
https://airs.jpl.nasa.gov/events/41

October 8-12, 2018
Precipitation Measurement Mission Science Team Meeting, Phoenix, AZ.
https://pmm.nasa.gov/meetings/all/2018-pmm-science-team-meeting

October 11-15, 2018
MODIS/VIIRS Science Team Meeting, Silver Spring, MD
https://modis.gsfc.nasa.gov/sci_team/meetings/201810/

January 22-24, 2019
Aura Science Team Meeting, Pasadena, CA.
https://mls.jpl.nasa.gov/aura2019/

April 1-4, 2019
ABoVE Science Team Meeting, La Jolla, CA.
https://above.nasa.gov/meeting_2019/index.html

Global Science Community

December 10-14, 2018
Fall Meeting of American Geophysical Union, Washington, DC.
https://fallmeeting.agu.org/2018/welcome/

January 6-10, 2019
American Meteorological Society, Annual Meeting, Phoenix, AZ.
https://annual.ametsoc.org/index.cfm/2019/

Undefined Acronyms Used in Editorial and Table of Contents

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
CALIPSO	Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations
CLARREO	Climate Absolute Radiance and Refractivity Observatory
CYGNSS	Cyclone Global Navigation Satellite System
GCOM-W1	Global Change Observation Mission—Water
GEDI	Global Ecosystem Dynamics Investigation
GOES	Geostationary Operational Environmental Satellite
GPM	Global Precipitation Measurement
GRACE-FO	Gravity Recovery and Climate Experiment Follow-On
GSFC	NASA's Goddard Space Flight Center
HQ	NASA Headquarters
JPL	NASA/Jet Propulsion Laboratory
LCLUC	Land Cover and Land Use Change
NOAA	National Oceanic and Atmospheric Administration
OCO-2	Orbiting Carbon Observatory-2
PI	Principal Investigator
SARI	South/Southeast Asia Research Initiative
SMAP	Soil Moisture Active/Passive
TIRS-2	Thermal Infrared Sensor-2
TRMM	Tropical Rainfall Measuring Mission
TROPICS	Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats

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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 1st of the month preceding the publication—e.g., December 1 for the January–February issue; February 1 for March–April, and so on.

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