Thirty Years Reporting on NASA's Earth Science Program

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Editor's Corner

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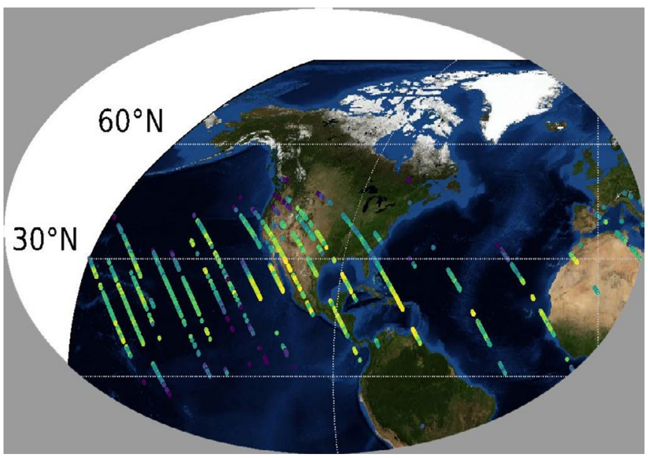
The International Space Station (ISS) is currently hosting six NASA Earth Science instruments. This editorial provides an update on several of these ongoing observations.[1]

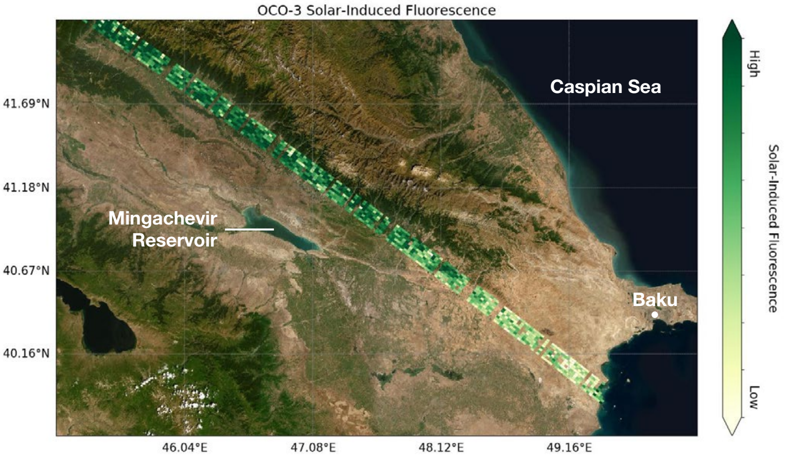
From its perch on the Japanese Experiment Module–Exposed Facility (JEM-EF), NASA's Orbiting Carbon Observatory-3 (OCO-3) captured its first observations of reflected sunlight on June 25, 2019. Just weeks later, the OCO-3 team made its first determinations of carbon dioxide (CO_2) and *solar-induced fluorescence* (SIF)—the glow that plants emit during photosynthesis—see images below.

OCO-3 launched to the space station on May 4, 2019, joining the OCO-2 mission, which completed its fifth year in orbit on July 2. Although one of the main objectives of the OCO-3 mission is to complement, and then eventually extend, the CO_2 and SIF data records started by OCO-2, OCO-3 is equipped with a new pointing mirror assembly that will allow scientists to map local variations in CO_2 from space more completely than can be achieved by OCO-2. In addition, the ISS orbit allows OCO-3 to see the same location on Earth at different times of day, and thereby allows scientists to track diurnal variations in CO_2. OCO-2, by contrast, is in a Sun-synchronous, near-polar orbit that provides greater coverage in latitude, but only allows it to gather data at local times near 1:30 PM.

[1] In addition to the ISS missions mentioned here, the Total and Spectral Solar Irradiance Sensor–1 (TSIS-1) is also currently operating on the ISS, installed at ExPRESS Logistics Carrier–3 (ELC-3), position 5. ExPRESS stands for Expedite the Processing of Experiments to the Space Station. The ISS has four ELCs, which were delivered to the station via the Space Shuttle.

continued on page 2





OCO-3 "first-light" images released. The top image shows CO_2 measurements obtained over the U.S. during OCO-3's first few days of science data collection. These initial measurements are consistent with measurements taken by OCO-3's older sibling, OCO-2, over the same area. The consistency between the two instruments indicates that although OCO-3 instrument calibration is not yet complete, it is on track to continue its (currently still operational) predecessor's data record. The bottom image shows solar-induced fluorescence (SIF) measurements over western Asia. Areas with lower plant glow—indicating less photosynthetic activity—are shown in light green; areas with higher photosynthesis activity are shown in dark green. As expected, there is significant contrast in plant activity from areas of low vegetation near the Caspian Sea to the forests and farms north and east of the Mingachevir Reservoir (near the center of the image). **Image credit:** NASA/JPL

In This Issue

As we've reported in previous issues of *The Earth Observer*, OCO-3's data will also complement data from two other Earth-observing missions that have recently been installed on the JEM–EF: ECOSTRESS (see photo on page 15 of this issue), which measures temperature stress and water use by plants (see example on page 18 of this issue), and GEDI, which assesses the amount of above-ground organic plant material present, particularly in forests. The combined data from these instruments will give scientists an unprecedented level of detail about how plants around the globe are responding to changes in climate and a more complete understanding of the carbon cycle.

The mission team expects to complete OCO-3's in-orbit checkout phase next month. They are scheduled to release official CO_2 and SIF data to the science community early next year.

Meanwhile at the ELC-1 position, the Lightning Imaging Sensor (LIS) on ISS continues to perform well. Although the prime mission concluded at the end of February 2019 (two years after launch), the excellent health of LIS and the great science benefit in continuing operations resulted in a decision by NASA Headquarters to extend the mission through at least September 2020. For the first time since its predecessor mission, the Optical Transient Detector (OTD)[2] that ended in 2000, LIS is gathering lightning observations for important midlatitude storms, as well as providing coverage of the continental U.S. and middle and southern Europe. (Observations from LIS on TRMM did not extend into these latitudes.)[3] Prior to LIS on ISS, OTD provided only five years of space-based observations north and south of 38° latitude, so there is great value in extending the time series observations of these climatically sensitive midlatitudes. Other activities that benefit from the mission extension include operational applications of real-time LIS data by several NOAA agencies, which are only now ramping up, and important synergistic observations with the European Space Agency's (ESA) Atmosphere-Space Interaction Monitor (ASIM) to help unravel the causes and mechanisms leading to terrestrial gamma-ray flashes (TGFs).

LIS on ISS has been continuously acquiring science data since its activation on February 27, 2017. (To see a climatology of lightning from the first two years of LIS on ISS observations, see page 26 of this issue.) It records the time, energy, and location of lightning within its field-of-view. Since lightning relates to both thunderstorm and other atmospheric processes, NASA, other agencies, and the science community are using these data for weather, climate, air quality, and other studies. During its prime mission, LIS on ISS measurements helped calibrate and validate the new Geostationary Lightning Mapper (GLM) instruments that fly on GOES-16 and -17.[4]

Moving over to ELC-4, the Stratospheric Aerosol and Gas Experiment III (SAGE III) on ISS, launched in February 2017, has been successfully collecting science data since July 2017 (over 20,000 total occultation events as of this writing).[5] The initial set of atmospheric data

[2] The Optical Transient Detector was a secondary scientific payload on the MicroLab-1 satellite, which was launched into orbit by a Pegasus rocket in 1995. It operated until 2000.

[3] The first LIS instrument launched on the joint NASA–Japan Aerospace Agency (JAXA) Tropical Rainfall Measuring Mission (TRMM) in 1997. TRMM operated until April 2015.

[4] To learn more about LIS on ISS, read "LIS on ISS: Expanded Global Coverage and Enhanced Applications" in the May–June 2016 issue of *The Earth Observer* [**Volume 28**, **Issue 3**, pp 4-14—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/May_June_2016_color%20508.pdf#page=4*].

[5] Occultation is a technique for pointing and locking onto the Sun or the Moon and scanning the limb of Earth's atmosphere as the Sun or Moon rises or sets.

collected from the SAGE III instrument was released publicly in October 2017, and the first lunar data was released in January 2018. The latest science data product (Version 5.1) is available to the public through the ASDC at LaRC (*https://eosweb.larc.nasa.gov*) and includes ozone (O_3), nitrogen dioxide (NO_2), water vapor, and aerosol data collected throughout the mission.

The SAGE III team continues to conduct science product validation activities with NOAA in Boulder, CO, and the National Institute of Water and Atmospheric Research (NIWA) in Lauder, New Zealand. SAGE III's measurements are primarily validated through lidar and balloon sondes. The team has successfully launched ozone and water vapor sondes from both locations, and is working on the development and launch of aerosol sondes.[6] The photograph on page 32 of this issue shows a unique view of the instrument, obtained from the perspective of OCO-3 as it was going through testing.

Continuing an impressive longevity record for NASA's fleet of Earth observing satellites, the joint NASA–USGS Landsat 7 mission celebrated the twentieth anniversary of its launch on April 15. Building upon a long record of heritage instruments and platforms, Landsat 7's technology included enhanced sensor characteristics with the Enhanced Thematic Mapper Plus (ETM+), as well as an advanced solid-state data recorder and a Long-Term Acquisition Plan that allowed for asynchronous data transmission. Coupled with discussion of a new data access policy that allowed users to access Landsat scenes free of cost, the anniversary article in this issue relates how Landsat 7 augmented Earth land-surface remote sensing. While there has long been an issue with its Scan Line Corrector, the USGS has deemed Landsat 7's data "…some of the most geometrically and radiometrically accurate of all civilian satellite data in the world." Our congratulations and thanks to the Landsat 7 team on their ongoing success. Turn to page 4 to learn more.

In the twenty years since Landsat 7's launch, the Landsat Program has continued to make strides. Landsat 8 was launched in 2013, and the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) instruments aboard continue to acquire high-quality imagery of the Earth's land areas. Landsat 9, a near copy of Landsat 8, has completed instrument development, and is set to begin operations in 2021. Finally, NASA and USGS are collaborating to define an architecture for the next generation of Landsat observations under the Sustainable Land Imaging Program, which could begin operations in the mid-2020s. Most importantly, the Landsat data archive remains a cornerstone of the land remote sensing community, with some 1500 peer-reviewed papers each year around the world citing the dataset.

Last but not least, NASA's Aura mission celebrated the fifteenth anniversary of its launch on July 15, 2019. Aura's two remaining operating instruments, the Microwave Limb Sounder (MLS) and Ozone Monitoring Instrument (OMI), continue to collect science-quality and trend-quality data for a number of trace gas constituents.[7] Aura data enable monitoring of the health of Earth's stratospheric ozone layer, as well as understanding the chemical and dynamical processes that affect it. In addition, they provide information on air pollution trends and variations around the world. The Aura Science Team will meet in Pasadena, CA from August 27-29, 2019, to discuss the latest science and applications. During the meeting, the OMI team will be presented the 2018 Pecora Award for "15+ years of sustained team innovation and international collaboration to produce daily global satellite data that revolutionized urban air quality and health research."[8] Look for a summary report on this meeting in a future issue of *The Earth Observer*. ■

[6] To learn more about SAGE-III on ISS, read "The SAGE Legacy's Next Chapter: SAGE III on ISS: Continuing the Data Record" in the November–December 2015 issue of *The Earth Observer* [**Volume 27**, **Issue 6**, pp. 4-11—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/Nov%20Dec%20 2015_508_col.pdf#page=4*].

[7] Aura has two other instruments that are no longer operational: The High Resolution Dynamics Limb Sounder (HIRDLS) operated until March 2008; the Tropospheric Emission Spectrometer (TES) operated until January 2018.

[8] To learn more about the accomplishments of the first ten years of the Aura mission, see "Aura Celebrates Ten Years in Orbit" in the November–December 2014 issue of *The Earth Observer* [**Volume** 26, **Issue 6**, pp. 4-17—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/November-December_2014_color_508.pdf#page=4*].

List of Undefined Acronyms in Editorial and Table of Contents

ABoVE	Arctic–Boreal Vulnerability Experiment
ASDC	Atmospheric Science Data Center
CERES	Clouds and the Earth's Radiant Energy System
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
ELC	ExPRESS logistics carrier
GEDI	Global Ecosystem Dynamics Investigation
GOES	Geostationary Operational Environmental Satellite
JPL	Jet Propulsion Laboratory
LaRC	NASA's Langley Research Center
NOAA	National Oceanic and Atmospheric Administration
USGS	United States Geological Survey

feature article

The Living Legacy of Landsat 7: Still Going Strong after 20 Years in Orbit

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Introduction

The twentieth anniversary of the launch of Landsat 7 on April 15, 1999, is an opportune time to retrace the history leading to modern Earth science data acquisition and use. This article provides a retrospective, with some insight into why Landsat 7 was a key player in Earth science and related technical endeavors, and how its mission has informed Earth system science to this day. It discusses some of the scientific and technology bases for the Landsat program generally and Landsat 7 specifically, and points out ways in which Landsat 7 crossed organizational boundaries to ensure the best scientific return. Other topics include a significant advance in storing and transmitting data, advances in sensor technology on Landsat 7 and an ongoing mechanical problem with that key sensor. The article closes with a few examples of how Landsat 7 advances Earth science, a summary of major benefits that continue to accrue from Landsat 7, and what's next for the platform.

Landsat Background and Basics

Humans use some 40% of Earth's land surface for agriculture, so it behooves us to address the health—or lack of health—of those areas. Human activities and natural phenomena both have caused significant environmental degradation that could—absent attention—have detrimental consequences for life on Earth.

The Landsat program was brought forth to enable better understanding of the land surfaces of our home planet—surfaces that we use intensively to support our continued existence on Earth.

The Landsat program was brought forth to enable better understanding of the land surfaces of our home planet—surfaces that we use intensively to support our continued existence on Earth. The program had its origins in the 1960s when NASA was tasked with developing low-Earth-orbiting capabilities to provide applications-type data to resource managers and to a budding cadre of Earth scientists who were just beginning to grasp the value of such platforms.

The prospect of placing satellites in low Earth orbit for remote sensing of Earth was raised by William Pecora—then-chief geologist of the U.S. Geological Survey (USGS)—in 1964; eight years later his proposal was realized with the launch of Landsat 1 [then known as the Earth Resources Technology Satellite-1 (ERTS-1)] in July 1972. Over time the program proved its mettle and value, resulting in an ongoing series of Landsat platforms.

Proof of Concept

Based on an augmented Nimbus platform the July 23, 1972, launch of Landsat 1 carried sensors and data-relay capabilities that set the tone and technology for several follow-on missions. For the first time, this allowed a structured means to provide routine, global, repetitive data acquisition of Earth's land surfaces that continues to the present day.

Demonstrating the increasing robustness of satellite platforms, Landsat 1 functioned well for its five years in orbit, before ceasing operations on January 6, 1978. Prior to that, however, Landsat 2 was launched on January 22, 1975—a week after NASA officially scrapped the name ERTS. Subsequent satellites in the series, Landsats 3, 4, and 5, were launched in 1978, 1982, and 1984, respectively.[1]

[1] For more on the Landsat legacy, see "Chronicling the Landsat Legacy" in the November–December 2011 issue of *The Earth Observer* [**Volume 23**, **Issue 6**, pp. 4-10—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Nov_Dec_2011_col_508.pdf#page=4*].

In 1984 Congress passed the Land Remote Sensing Commercialization Act. This legislation began the ill-fated Landsat commercialization era, during which the use of data for research plummeted. Under this law, the Earth Observation Satellite Company (EOSAT) Corporation was selected in 1985 to commercialize Landsat and continue the program. EOSAT developed Landsat 6, which was launched in 1993; unfortunately, this satellite did not achieve orbit. Landsat 5, then 12 years past its design life, continued to function but was operated by EOSAT, which attempted commercialization with less-than-desired results. For example, per-scene costs of $4,000 to $6,000 were impractical in the marketplace, thereby limiting use.

Beginning to Think Globally

By the early 1990s there was a growing consensus about the critical role of Earth observation data for global change research. There was enough support in the science community for such data that the National Space Council recommended that Landsat 7—the next in the Landsat series of satellites—be built and operated by the U.S. government to ensure a continuous global data archive of medium-resolution data for long-term monitoring of Earth's land surfaces. These recommendations formed the basis for the *U.S. Land Remote Sensing Policy Act*, which Congress passed in 1992.

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After the realization that commercialization of the Landsat program did not help—and, in fact, hampered—Earth system science research, the Land Remote Sensing Policy Act of 1992 explicitly recognized the importance of remote sensing data. It also called for the U.S. to more firmly establish and maintain significant leadership in land-remote-sensing technology. The Act noted the longevity of the Landsat series and the importance of maintaining continuity of these valuable and irreplaceable datasets. It also noted that the high costs of Landsat scenes (due to commercialization) were impeding the use of such data by a wider community of interested parties. Fortunately, from early on, the U.S. Geological Survey (USGS) provided archive and distribution of Landsat data via their Earth Resources Observation and Science (EROS) Center, including a reduced—but nonetheless essential—role during the commercialization period.

Figure 1. The Landsat 7 spacecraft after instrument integration at the Lockheed Martin Missiles and Space facility in Valley Forge, PA. **Image credit:** NASA

The Spacecraft

Landsat 7 (see **Figure 1)** was launched on a Delta II expendable launch vehicle from the Western Test Range, Vandenberg Air Force Base, CA. The spacecraft bus was built under contract to NASA by Lockheed Martin Missiles and Space in Valley Forge, PA; the single instrument, the Enhanced Thematic Mapper Plus (ETM+), discussed in more detail here, was built under contract to NASA by Raytheon Santa Barbara Research Center in Santa Barbara, CA. Continuing the configuration of the system used since Landsat 4, Landsat 7 is in a Sun-synchronous orbit, at an inclination of 98.2°, with repeat coverage of 16 days.[2]

[2] Landsats 1-3 used a different, higher orbital configuration, with an 18-day repeat cycle. With Landsat 4, the orbit altitude was decreased to accommodate the Thematic Mapper instrument. This orbit has been used in the Landsat Program since then.

Landsat 7 was designed and built on an evolving legacy of satellite and instrument technology, with results outlined in **Table 1.**

Table 1. Landsat 7 basic physical parameters.

Characteristic	Comments
Power	Sun-tracking solar array; two 50-AHr NiCd batteries
Attitude control	Four reaction wheels; three two-channel gyros; static Earth sensor; torque rods; magnetometer
Orbit control	Monopropellant hydrazine system with 12 one-pound-thrust jets
Weight	2200 kg (4850 lb)
Length	4.3 m (~14 ft)
Diameter	2.8 m (~9 ft)
Data Recording	Solid-state recorder (SSR)
Data rate	150 Mbps

The Heritage of a Key Sensor

The first major change in sensors came with Landsats 4 and 5, which not only carried a copy of the Multispectral Scanner sensor but also a more advanced multispectral scanner, called the Thematic Mapper (TM).

With the long history of Landsat activities, improvements over time at all levels of mission criteria are to be expected. **Table 2** on page 7 provides a concise summary of both the chronological history and the evolving instrument capabilities of each Landsat mission to date; note that Landsat 8 is included here for completeness. The remainder of this section expands upon what is summarized in Table 2.

The instruments on the first three Landsat satellites reflected the state of technology available at the time. Landsats 1-3 carried the same complement of sensors: the Multispectral Scanner (MSS) and Return Beam Vidicon (RBV). The RBV was a simple television camera that never matched the wealth of data provided by the MSS. The RBV sensor on Landsat 1 failed shortly after the satellite began to operate in orbit (almost taking out the entire mission!). The same RBV sensors were used on Landsat 2, but little use was made of these images as the MSS data quality was so much better. On Landsat 3 the RBV was converted to a single panchromatic sensor with a 40-m spatial resolution; geologists found these images particularly useful. The MSS was designed such that its scanning geometry relative to Earth's surface and rotation provided a global dataset, with six detectors for each of the four spectral bands, covering the spectrum from the visible-green to the near infrared (NIR) regions. The MSS on Landsat 3 added a fifth band in the thermal infrared (TIR); unfortunately, it failed shortly after launch.

The first major change in sensors came with Landsats 4 and 5, which not only carried a copy of the MSS sensor but also a more-advanced multispectral scanner, called the Thematic Mapper (TM). The TM, like the MSS, measured reflected solar radiation, but with refined spectral bands and the addition of a blue spectral band and two bands covering parts of the shortwave infrared spectrum. It also included a TIR band. The TM uses sixteen detectors per band, with a finer 30-m spatial resolution compared to the 80-m MSS spatial resolution.

When Landsat 7 was launched, the Enhanced Thematic Mapper Plus (ETM+) instrument onboard was the most sophisticated Landsat sensor yet.

When Landsat 7 was launched, the ETM+ instrument onboard was the most sophisticated Landsat sensor yet. ETM+ carried a new 15-m panchromatic band and had a refined thermal band with a 60-m (197-ft) spatial resolution (compared to 120 m (394 ft) for Landsats 4 and 5). Landsat 7 also utiltized a new solid-state data recorder (SSR)—the first to fly on a civilian mission—as described in *New Capabilities for Landsat 7* on page 9.

Table 2. Landsat mission characteristics.*

Satellite	Launch Date (End of Service)	Sensor	Resolution (m) and Spectral Range	Communication Mode	Alt. (km)	Repeat (days)
Landsat 1 (ERTS-1)	July 23, 1972 (January 6, 1978)	RBV	80/VNIR	Direct downlink + recorders	917	18
		MSS	80/VNIR			
Landsat 2 (ERTS-2)	January 22, 1975 (July 27, 1983)	RBV	80/VNIR	Direct downlink + recorders	917	18
		MSS	80/VNIR			
Landsat 3	March 5, 1978 (September 7, 1983)	RBV	40/PAN	Direct downlink + recorders	917	18
		MSS	80/VNIR 240/TIR			
Landsat 4	July 16, 1982 (June 15, 2001)	MSS	80/VNIR	Direct downlink + TDRSS	705	16
		TM	30/VNIR, SWIR 120/TIR			
Landsat 5	March 1, 1984 (June 5, 2013)	MSS	80/VNIR	Direct downlink + TDRSS	705	16
		TM	30/VNIR, SWIR 120/TIR			
Landsat 6	*(October 5, 1993)*	*ETM*	*15/PAN 30/VNIR, SWIR 120/TIR*	*Direct downlink + recorders*	*705*	*16*
Landsat 7	April 15, 1999 (still operating)	ETM+	15/PAN 30/VNIR, SWIR 60/TIR	Direct downlink + SSR	705	16
Landsat 8	February 11, 2013 (still operating)	OLI	15/PAN 30/VNIR, SWIR	Direct downlink + SSR	705	16
		TIRS	100/TIR			

* *Alphabetic listing of acronyms in Table 2.* ETM: Enhanced Thematic Mapper; ETM+: Enhanced Thematic Mapper Plus; MSS: Multispectral Scanner; OLI: Operational Land Imager; PAN: Panchromatic; RBV: Return Beam Vidicon; SSR: Solid State Recorder; SWIR: shortwave infrared; TIR: thermal infrared; TIRS: Thermal Infrared Sensor; TDRSS: Tracking and Data Relay Satellite System; TM: Thematic Mapper; VNIR: visible/near-infrared.

** Landsat 6 failed to reach orbit. This row lists what would have been.

Table credit: USGS

Early Success, but with a Long-Term Problem

While the launch and subsequent checkout of Landsat 7 went well, after four flawless years of operation, problems emerged. On May 31, 2003, the Scan Line Corrector (SLC) failed, resulting in lack of data in several narrow wedge-shaped slivers on acquired scenes. The SLC's role was to compensate for the orbital motion of the platform during forward and return scans to create parallel sweeps across the Earth's surface; without it, a zig-zag pattern results, as depicted in **Figure 2** on page 8. The problem continues to the present, with a loss of some 22% of Earth surface coverage in each image.

As devastating as this failure was and with no remedy available, the remaining data are still, as USGS describes, "…some of the most geometrically and radiometrically accurate of all civilian satellite data in the world." The landmark 2008 USGS decision

As devastating as this failure [with the Scan Line Corrector] was and with no remedy available, the remaining data are still, as USGS describes, "…some of the most geometrically and radiometrically accurate of all civilian satellite data in the world."

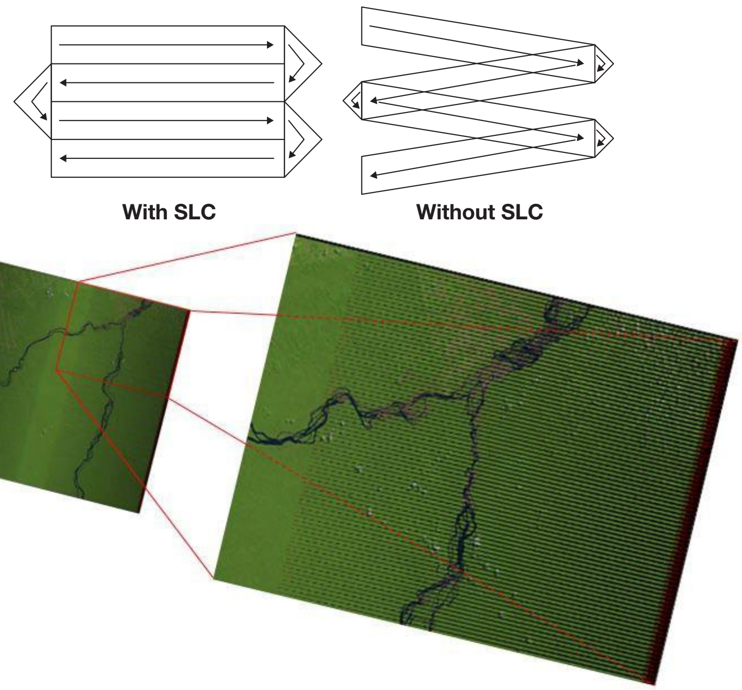

Figure 2. The failure of the SLC produces a zig-zag pattern [*compare top left diagram to top right*] that is evident in all Landsat 7 data collected since May 31, 2003, as shown in the image [*bottom left*], and particularly apparent in the closeup [*bottom right*]. **Image credit:** USGS

to make all Landsat data free and openly available, the mission automated long-term acquisition plan (LTAP) operations, and newly explored image compositing methods somewhat reduced the impact of the SLC failure. In some, if not all, cases two or more scenes of the same location could be composited to produce essentially cloud-free and gap-free observations.

Data Access Policy Changes

By removing the commercial copyright protections on the imagery, and lowering the price to $600 per scene, newly acquired 30-m Landsat data could be more easily procured and shared. However, the $600 per-scene cost still limited regional and global studies, particularly over extended time periods. In 2008, when USGS removed the cost for online data, the use of the imagery skyrocketed—as evident in **Figure 3**.

continued on page 10

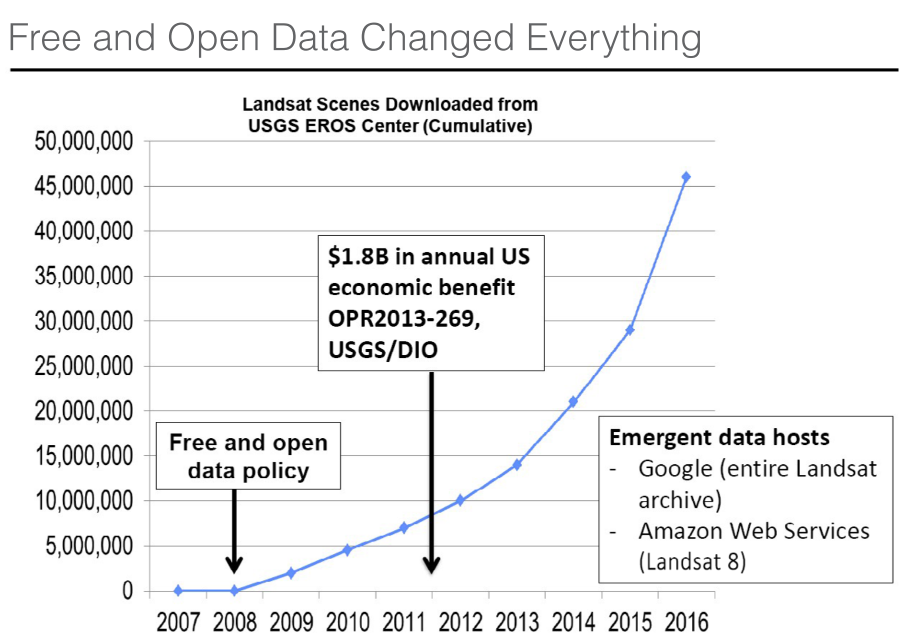

Figure 3. The download rate for Landsat data has increased rapidly since USGS removed the cost for online data access. This graph includes only downloads from the USGS EROS. [Google delivers approximately one-billion Landsat scenes to users per month, and Amazon Web Services (AWS) delivered that volume of scenes in its first year online (2015)]. The citation for U.S. economic benefit comes from USGS/Department of the Interior (DOI) data. **Image credit:** USGS

New Capabilities for Landsat 7

Landsat 7 incorporated several technological advances into its design. The most significant were in the area of onboard data recording and data quality assurance via calibration and validation.

Onboard Data Recording and Asynchronous Data Transmission

The first-generation Landsat satellites (1-3) carried massive 76-lb (34.4-kg) tape recorders with lots of moving parts, ~549 m (~1800 ft) of magnetic tape, and an inability to function for the length of a mission. For example, the first three Landsats used reel-to-reel tape recorders that were reliable for about the first year of each mission—and then the tapes wore out. Because of these repeated failures, the second-generation Landsat satellites (4 and 5) eschewed onboard recorders, relying instead on relay satellites. But relay costs and the satellites' commercialization worked against global coverage.

A significant advance in the Landsat 7 mission design was the inclusion of a solid-state data recorder (SSR). For the first time in the Landsat program history, Landsat 7 was equipped with hardware that could store large amounts of imaged data onboard for later download when a ground station was in range, i.e., *asynchronous data transmission*.

Long-Term Acquisition Plan

Unlike its predecessors, Landsat 7 employed an automated long-term acquisition plan (LTAP) that had as a goal "global acquisition of essentially cloud-free observations." This approach was developed to meet the Landsat 7 mission goals of supporting Earth system science.

When combined with the SSR, the LTAP enabled the best global coverage the program had ever known by acquiring data under best conditions for scientific purposes and storing them on the SSR for subsequent transmission to ground stations when appropriate.

Data Quality: Calibration and Validation

Landsat 7 also offered improved geometric and radiometric calibration compared to its predecessors. Onboard, Landsat 7 added partial- and full-aperture solar calibrators to the existing complement of two calibration lamps. On the ground, Landsat 7 was the first Landsat mission to incorporate a data-trending image assessment system into the operational ground system.

During its ascent into orbit, Landsat 7 collected data as it flew under Landsat 5. This enabled the cross-calibration of Landsats 5 and 7, and in 2013 Landsat 8 underflew Landsat 7 for the same purpose. Additionally, a team of calibration scientists have also overseen in-the-field vicarious calibration efforts, which make certain that satellite measurements agree with physical ground-based measurements. Careful data calibration ensures that the Landsat data record can show meaningful trends of land use and land cover change—even when the changes are subtle. One example of such change is the forest disturbance that occurs over time as a result of increasing insect damage.

Demand for Landsat Data

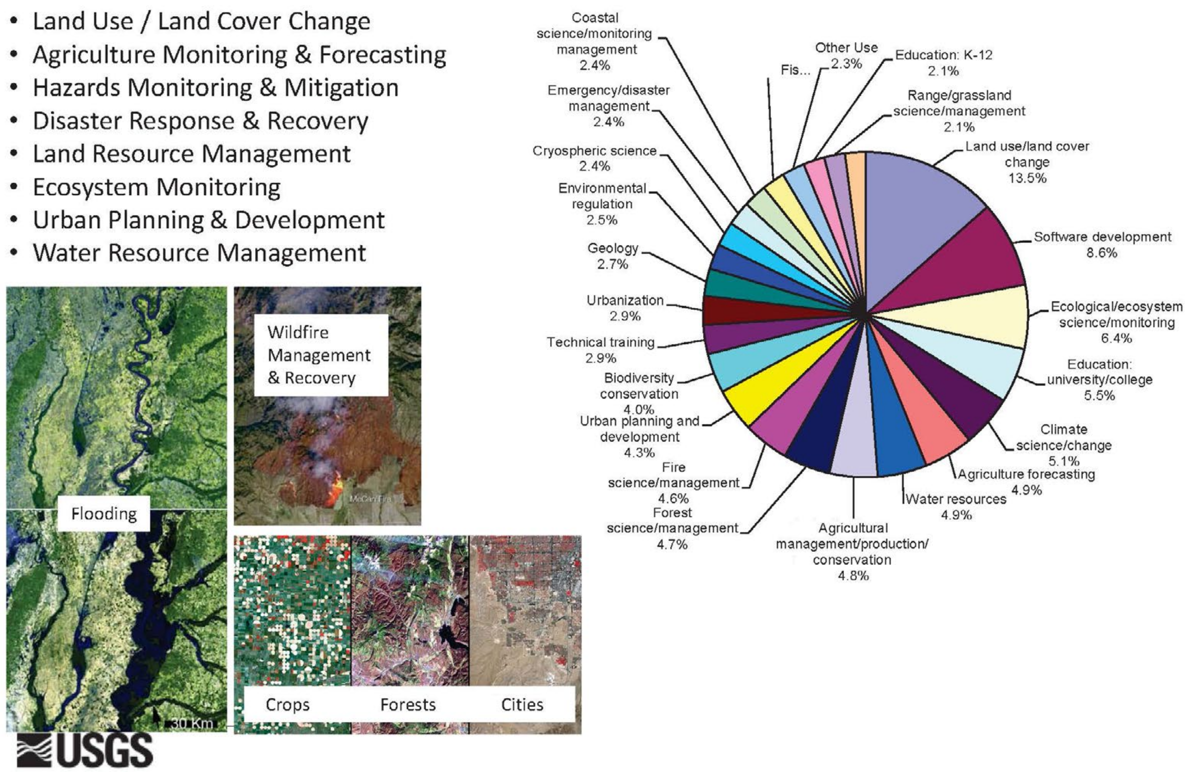

Figure 4. Demand for Landsat data comes from a wide range of interested communities and stakeholders, from the largest group (land use/land cover change) to the smallest (range/grassland science and management). **Image credit:** USGS

Coupled with dramatically lower costs for computing power, this move led to a revolution in use: Data analyses went from relatively small subscene/local studies, to regional, continental, and even global-scale studies. An analysis of how the various data are used is shown in **Figure 4.**

Integration with Data from Other Missions

Landsat 7 and NASA's Earth Observing System (EOS) flagship platform, Terra, also launched in 1999, were placed into orbit such that Landsat 7 is about 30 minutes ahead of Terra in the so-called "Morning Constellation".[3] This enabled the two satellites to capture congruent and near-synchronous data when vegetation and atmospheric conditions were similar.

This cross-mission integration is still producing benefits today, with a multitude of data fusion products from Landsat and the Moderate Resolution Imaging Spectroradiometer (MODIS) on Terra. One such outcome is the highly regarded Spatial and Temporal Adaptive Reflectance Fusion Model (STARFM), which has improved global agricultural monitoring. STARFM was designed to combine MODIS data with Landsat data to produce synthetic Landsat-like imagery on a daily basis.

Major Benefits from Landsat 7

Benefits from Landsat 7 fall into four main categories: technical, scientific, programmatic, and organizational. While some of the benefits were discussed earlier, the information that follows revisits these items and provides new introductions so that the full impact of Landsat 7 on Earth remote sensing across a wide range of categories may be easily grasped.

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[3] For more on the Morning Constellation, see "Earth Science Mission Operations, Part I: Flight Operations—Orchestrating NASA's Fleet of Earth Observing Satellites" in the March–April 2016 issue of *The Earth Observer* [**Volume 28**, **Issue 2**, pp. 4-13—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Mar_Apr_2016_508_color.pdf#page=4*].

Technical Benefits

Lessons learned with the TM on Landsats 4 and 5 led to making the ETM+ the best-calibrated Landsat imager, allowing it to act as a cross-calibration source for other sensors on other platforms. Also, the implementation of the SSR onboard made possible the development of an automated LTAP that could yield nearly global, seasonal observations. This set the standard for all future Landsat missions. In the process, the Landsat 7 team developed and implemented a routine, randomly sampled image-assessment system to ensure data quality standards were being met.

Lessons learned with the TM on Landsats 4 and 5 led to making the ETM+ the best-calibrated Landsat imager, allowing it to act as a cross-calibration source for other sensors on other platforms.

Scientific Benefits

As discussed previously, the purposeful placement of Landsat 7 and the EOS Terra platform in the Morning Constellation, spaced about 30 minutes apart, allowed the respective Science Teams to optimize the scientific utility, e.g., capturing terrestrial ecosystems at multiple patial and spectral resolutions under nearly identical plant physiological conditions.

The major research area of plant response to stress came under the auspices of the North American Carbon Program, under which the North American Forest Dynamics (NAFD) Project generated integrated forest disturbance maps for the conterminous U.S. from 1986–2010, as represented in **Figure 5.** These time-integrated maps clearly demonstrated that some 20% of mapped locations experienced some form of disturbance over the study period, with consequences for the North American carbon cycle.[4]

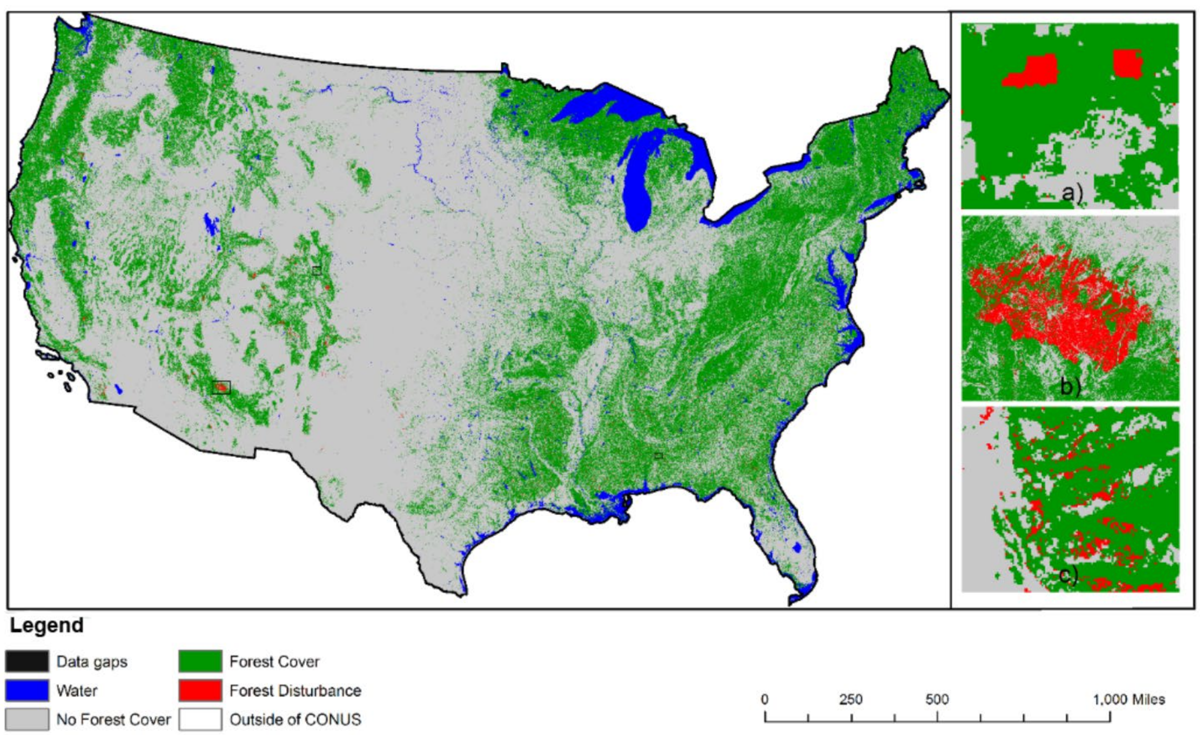

Figure 5. An example of an annual (2002) disturbance map from the NAFD Project. Insets on the right reveal the high spatial resolution of detected disturbances. *Top:* Forest harvesting in Butler County, AL; *middle:* Massive Rodeo-Chediski fire in Navajo County, AZ; and *bottom:* Mountain pine beetle damage in Grand County, CO. **Image credit:** ORNL DAAC/Sam Goward

In a significant development and with considerable planning and implementation to acquire as much imagery of the continent as possible, over 1000 Landsat 7 scenes were chosen to create the then-highest resolution image mosaic of Antarctica, the Landsat Image Mosaic of Antarctica (LIMA). LIMA was instituted as part of the International Polar Year (2007–2008). Supporting organizations included NASA, USGS, and the British Antarctic Survey. The program had several goals, including supporting polar research and an outreach component designed to make Antarctica and physical changes there more accessible to the general public. Images obtained for LIMA include a vast array of high-resolution images suitable for such purposes,

[4] For more information on NAFD, visit *https://landsat.gsfc.nasa.gov/watching-a-quarter-century-of-north-american-forest-dynamics-with-landsat.*

as exemplified in **Figure 6**. As **Robert Bindschadler** [NASA's Goddard Space Flight Center—*LIMA Project Lead*] said at the time, "The revolutionary concept of systematic collection of Landsat 7 data timed to optimize anticipated scientific applications will make possible a global monitoring of the cryosphere with a dataset heretofore only available in limited regions."

Figure 6. Over 1000 images from the LIMA dataset were used to generate this mosaic of the Ferrar Glacier at 15-m (~49-ft) spatial resolution. At the time it was generated, this was the most detailed such image of Antarctica ever generated. **Image credit:** NASA

Another first was the Millennium Coral Reef Mapping Project in 2006, in which Landsat 7 data were used to create a first-of-its-kind global survey of coral reefs. The research lead on this project, **Frank Muller–Karger** [University of South Florida, *Director of the Institute for Marine Remote Sensing*] commented in 2015 that, "Until we made the map of coral reefs with Landsat 7, global maps of reefs had not improved a lot since the amazing maps that Darwin drafted." An example of an image that facilitated this research is shown in **Figure 7**. As with LIMA, considerable effort went into scheduling and sensor preparation to allow a wide array of scenes.

Figure 7. Coral reefs in the vicinity of Vanua Levu, Fiji's second-largest island, acquired on September 19, 2002. **Image credit:** NASA

In general terms, Landsat 7 thermal infrared imagery with its 60-m resolution could be used to estimate evapotranspiration (i.e., water uptake and release) from crops and the soil they grow in—down to the level of individual agricultural fields. This enabled major advances in water use management (i.e., irrigation practices).

Further, the 30-m resolution of the ETM+ provides an excellent match with the scale of human activities, so the massive increase in holdings in the Landsat image archive allows a clearer look at the impacts of those activities on the planet's various systems. Being able to translate from local, to regional, continental, and even global scales depending on the phenomena being investigated was a welcome development.

Programmatic Benefits

With the advent of Landsat 7, contributions to global change research were considered of major importance by providing detailed human-scale measurements of land conditions and dynamics. The return to government operations and contemporary mission configuration facilitated this major transition to Landsat scientific research, not least because of the massive changes in data access policies and their subsequent implementation.

When Landsat was first proposed it was mainly considered an applications—not science—mission. There was a first call for proposals in 1971 that lasted until 1972 and explored many uses. In 1973 Congress directed NASA to use Landsat for agricultural monitoring, after the then-Union of Soviet Socialist Republics (USSR) caused difficulty in the commodities (e.g., wheat) market.

Although it was clear that land dynamics probably played important roles in Earth system science, Landsat was rarely used for this purpose until the late 1980s. Indeed, the agricultural focus lasted until Landsat was commercialized in 1986, but when Landsat was returned to government operations in 1992, NASA directed it to service the needs of Earth system science.

Organizational Benefits

For the first time in the Landsat program, NASA and USGS selected a Science Team to support the Landsat 7 mission. This science team represented myriad scientific interests including agriculture, cryosphere, clouds, coastal zones and coral reefs, tropical and temperate forestry, land cover, geography, and geology, as well as foundational support for radiometric calibration of optical and thermal measurements and atmospheric corrections. The Science Team is now in its third complement, and continues to support the mission admirably.

The work of these team members, as well as NASA and USGS staff, led to the development of Landsat data products suitable for time series studies at regional-to-global scales, clearly demonstrating the benefits of interorganizational communication and participation.

The work of these team members, as well as NASA and USGS staff, led to the development of Landsat data products suitable for time series studies at regional-to-global scales, clearly demonstrating the benefits of interorganizational communication and participation.

The Future of Landsat 7

As with all such missions, end-of-life planning is a major part of the mission. Throughout its lifetime, Landsat 7 has undergone several orbital maneuvers to ensure that the local-mean-time (LMT) data acquisitions are maintained. The final such "Delta-I" (i.e., change in inclination) maneuver took place on February 7, 2017. From that point forward, the satellite's orbit has begun to slowly degrade (lower) such that by 2020 the LMT will fall back from the desired 10:00 AM LMT to about 9:15 AM.

By the time of the planned launch of Landsat 9 late in 2020, Landsat 7's orbit will have degraded such that Landsat 9 can move into the 705-km (438-mi) "standard" orbit altitude, and take Landsat 7's place in an orbit that allows data to be collected eight days out of phase with Landsat 8 (with two satellites in orbit, a Landsat scene is collected over every location on Earth every eight days). Landsat 7's 9:15 AM LMT acquisition will preclude acquiring high-quality and heritage-continuing data, and the satellite will be decommissioned.[5]

In a new era of efficiency and competition for limited resources, plans are underway to explore the possibility of using NASA's Restore-L Robotic Servicing Mission[6] to refuel and service Landsat 7, primarily to ensure successful decommissioning, but also to provide the possibility of turning the satellite into a transfer radiometer. This would allow it to act as a calibration instrument for Landsats 8 and 9, and perhaps even extend its scientific utility.

[5] To minimize orbital debris, space policy requires that adequate propellant be reserved to conduct orbit adjustment burns to rapidly remove a satellite from orbit once it is declared inoperable.

[6] For more on the NASA Restore-L Robotic Servicing Mission, see *https://sspd.gsfc.nasa.gov/restore-L.html.*

Earth Insights

With capabilities such as those afforded by the Landsat program worldwide—and described in this article—Earth system changes are observed in both real-time and across time, the latter providing a longer-term view on how Earth's various systems interact with each other across long (by human standards) time scales. Many systems are affected, including "…human health, agriculture, climate, energy, fire, natural disasters, urban growth, water management, ecosystems and biodiversity, and forest management," according to NASA.[7]

In summary, among its other significant advances, we note that:

- by continuing the increasingly long record of land-surface phenomena, Landsat 7 offered *mission continuity* for the Landsat program;
- with the *absolute calibration* provided by its onboard capabilities, Landsat 7 provides not only high-quality data but also on-orbit, cross-calibration capability for other Earth-science missions;
- with its repeated data acquisitions under sunlit, cloud-free conditions, Landsat 7's *global survey mission* offered a closer look at our planet's interacting systems; and
- by providing free access to already acquired scenes, interested parties—be they researchers or decision makers—have enhanced ability to manage Earth's resources and, potentially, to reduce the impact of human activities on vital systems.

From its inception to the present day the Landsat program has provided us with broad and deep insights into our planet's land surfaces and uses.

Conclusion

From its inception to the present day the Landsat program has provided us with broad and deep insights into our planet's land surfaces and their uses. Each successive Landsat platform has made contributions to relevant and useful data sets. Landsat 7 continued that trend, and its follow-on missions further build upon that legacy: Landsat 8 is currently in orbit and Landsat 9 is scheduled for launch in late 2020.

Absent the sheer volume and high quality of such moderate-resolution data, we would not possess our current deep and broad understanding of our home planet's land-surface systems and how they interact with other Earth systems.

Acknowledgments

The authors gratefully acknowledge the editorial aid provided by Ernest Hilsenrath, Alan Ward, and Claire Parkinson in bringing this article to its current state of polish.

Sources for Additional Information on Landsat 7

Websites
https://landsat.gsfc.nasa.gov/landsat-7
https://www.usgs.gov/land-resources/nli/landsat/landsat-7

Data Users Handbook
https://www.usgs.gov/media/files/landsat-7-data-users-handbook

Book
Goward, S.N., et al. (2017), Landsat's Enduring Legacy: Pioneering Global Land Observations from Space. Bethesda, MD: American Society for Photogrammetry and Remote Sensing. ISBN 1-57083-101-7

Journal Article
Wulder, M.A. et al. (2019) "Current status of Landsat program, science, and applications." *Remote Sensing of Environment* **225:**127-147 *https://www.sciencedirect.com/science/article/pii/S0034425719300707.* ■

[7] See *https://landsat.gsfc.nasa.gov/how_landsat_helps* for additional information.

ECOSTRESS 2019 Workshop Summary: Science, Applications, and Hands-On Training

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Introduction

On March 21, 2019, the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) team, in conjunction with the Land Processes Distributed Active Archive Center (LP DAAC),[1] convened a one-day workshop at the California Institute of Technology in Pasadena, CA. Over 60 attendees participated in person and another 25 participated remotely through WebEx remote conferencing software, with direct support and engagement from workshop organizers on Slack. The objectives of the workshop were to provide a summary of mission status and science data to date, as well as provide an open-source, open-registration hands-on workshop on how to access, analyze, and visualize ECOSTRESS evapotranspiration (ET) data. The hands-on workshop accommodated over 25 in-person participants and, for those unable to travel, also accommodated 15 remotely.

[1] LP DAAC is one of several discipline-specific data centers within NASA's Earth Observing System Data and Information System (EOSDIS). The LP DAAC is located at the U.S. Geological Survey (USGS) Earth Resources Observation and Science (EROS) Center in Sioux Falls, SD. To learn more, visit *https://lpdaac.usgs.gov*.

After providing some brief background and status updates on the importance of ET and other water stress measurements and the goals for ECOSTRESS, this article summarizes the workshop. The full presentations are available at *https://ecostress.jpl.nasa.gov/documents/science-team-meeting-march-2019/science-team-meeting-march-2019*. The hands-on training materials are available at *https://lpdaac.usgs.gov/resources/e-learning/hands-workshop-accessing-processing-and-analyzing-ecostress-data.*

Background for Workshop

Launched in June 2018, ECOSTRESS is a thermal radiometer instrument that currently flies onboard the International Space Station's (ISS) Japanese Experiment Module–Exposed Facility (JEM-EF)—see photo below. The primary mission of ECOSTRESS is to advance understanding of vegetation response to changes in water availability as well as to characterize how ET changes on a diurnal scale. ECOSTRESS also seeks to apply these data to support agricultural vulnerability assessments, drought monitoring, and response applications. To do this, ECOSTRESS is delivering high-spatial-resolution data [70-m (~230-ft) pixels]. The data are derived from

This photo shows the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS), installed on the International Space Station's Japanese Experiment Module–Exposed Facility (JEM-EF). ECOSTRESS measures the temperature of plants and uses that information to better understand how much water plants need and how they respond to stress. **Image credit:** NASA radiance, which is converted to land surface temperature and emissivity, which is used to generate evapotranspiration, evaporative stress index, and water use efficiency on a variable (> seven-day) temporal repeat. Diurnal sampling is applied for priority targets such as the Continental U.S. and other key biomes around the world. The **Table** below lists the Level-1 (L1) through L4 ECOSTRESS data products.

ECOSTRESS represents one of several NASA Earth Science assets that are currently onboard the ISS, three of which are collocated on the JEM-EF.[2] Besides ECOSTRESS, the Global Ecosystem Dynamics Investigation (GEDI), launched in December 2018, which uses a lidar to characterize terrestrial ecosystems' structure and responses to changing climate and land use, is mounted on JEM-EF. Further, the Orbiting Carbon Observatory-3 (OCO-3), launched May 4, 2019, is now installed and operating on JEM-EF. OCO-3 will assess the distribution of carbon dioxide on Earth, including sources and sinks. Concurrent measurements from these missions demonstrate how the ISS offers a platform for highly synergistic Earth remote sensing measurements. In addition to these three NASA missions, two international assets obtain complementary measurements: the German Deutsches Zentrum für Luft- und Raumfahrt's (DLR) Earth Sensing Imaging Spectrometer [DESIS], a visible-to-near-infrared (VNIR) imaging spectrometer already onboard ISS, and the Japan Aerospace Exploration Agency's (JAXA) visible-to-shortwave-infrared (VSWIR) spectrometer/Hyperspectral Imager Suite (HISUI), is scheduled to launch later in 2019.

The key parameter needed to address the ECOSTRESS science questions is ET—see L3 data products in the Table below. ET is a key parameter for understanding how ecosystems are responding and adapting to changes in water availability and other environmental stressors. This is particularly true when measurements of ET are combined with other vegetation water-stress metrics. For example, drought and vegetation water stress can also be determined through analyzing precipitation anomalies, soil moisture—particularly at the root

[2] Other currently operating NASA missions on ISS (besides those mentioned in the text) include the Lightning Imaging Sensor (LIS) on ISS, the Stratospheric Aerosol and Gas Experiment–III (SAGE-III) on ISS, and the Total and Spectral Solar Irradiance Sensor–1 (TSIS-1).

Table. ECOSTRESS Data Products.

Data Product	Description	Pixel Size (m)*
ECO1BRAD.001	Radiance	70 × 70
ECO1BATT.001	Attitude and Ephemeris	70 × 70
ECO1BMAPRAD.001	Projected Radiance	70 × 70
ECO1BGEO.001	Geolocation	70 × 70
ECO2LSTE.001	Land Surface Temperature and Emissivity	70 × 70
ECO2CLD.001	Cloud Mask	70 × 70
ECO3ETPTJPL.001	Evapotranspiration (PT-JPL model enhanced)	70 × 70
ECO3ANCQA.001	Ancillary Data Quality	70 × 70
ECO3ETALEXIU.001	Evapotranspiration (ALEXI model enhanced)	30 × 30**
ECO4ESIPTJPL.001	Evaporative Stress Index derived from L3_ET_PT-JPL	70 × 70
ECO4ESIALEXIU.001	Evaporative Stress Index derived from L3_ET_ALEXI	30 × 30**
ECO4WUE.001	Water Use Efficiency	70 × 70

* This column would more accurately be labeled "**Pixel Spacing Resolution** (m)" because it is dependent on the altitude of the ISS, which is not constant.

** The 70 × 70-m pixel size is resampled to 30 × 30 m for this product.

NOTES

- All products are now publicly available through LP DAAC (*https://lpdaac.usgs.gov/news/release-ecostress-higher-level-products*) and also at *http://earthdata.nasa.gov*.
- **Median Latency** for processing is 12 hours.
- **Temporal Resolution** for ***all*** products is between 1–7 days over Continental U.S. and "target areas" as defined at *https://ecostress.jpl.nasa.gov/gmap*. See map where data has been acquired at *https://ecostress.jpl.nasa.gov/gmap/eco_map2*.
- **Undefined acronyms in the Description column**: PT-JPL stands for Priestley–Taylor Jet Propulsion Laboratory, a widely used model simulation for ET; ALEXI stands for Atmosphere Land Exchange Inverse, a multisensor thermal infrared approach to ET mapping.

zone—evaporative stress index (L4 product),[3] water use efficiency (L4 product),[4] and normalized difference vegetation index (NDVI).[5] One advantage of focusing on ET is that it is an indicator of vegetation stress that can manifest before browning is detected by NDVI—which allows an earlier indicator of drought onset. By leveraging the vantage point of space, research and applications communities are able to characterize these responses on a global scale. With diurnal sampling, ECOSTRESS is enabling insights on ET variability and response to water availability at higher spatial resolution and temporal frequency than has been possible before.

Workshop Overview

The one-day workshop was divided into a morning plenary session and the afternoon hands-on training session on the use of ECOSTRESS data, both of which are summarized below.

Morning Plenary Session on Science and Applications

The morning session consisted of presentations given on behalf of the ECOSTRESS Team, and also from LP DAAC representatives. Some of the highlights included a review of the history and timeline for development of the ECOSTRESS mission.

Simon Hook [NASA/Jet Propulsion Laboratory (JPL)—*ECOSTRESS Principal Investigator (PI)*] and **Dana Freeborn** [JPL—*ECOSTRESS Project Manager*] reviewed the mission's selection as an *Earth Venture Instrument* mission—cost-capped at $30M—with highly unique science objectives that leverage the ISS's precessing orbit to advance understanding of diurnal variability of evapotranspiration. They also discussed other ECOSTRESS science objectives, which include better understanding of vegetation response to changes in water availability and improving assessments of agricultural vulnerability and drought onset.

Hook and Freeborn also discussed the status of ECOSTRESS science acquisitions, which were impacted by an anomaly on the mass storage units. ECOSTRESS has now switched to direct playback, or file streaming, which allows ECOSTRESS to acquire more data than was possible previously. Quicklook images of the data are available at *https://ecostress.jpl.nasa.gov/gmap*.

[3] The Evaporative Stress Index (ESI) highlights areas with anomalously high or low rates of water use across the land surface and can be used to track changes in ET over time.
[4] Water use efficiency measures the ratio of water used in plant metabolism to water lost by the plant through transpiration.
[5] NDVI is a simple graphical indicator used to assess whether the target being observed contains live green vegetation or not. It is calculated by measuring the difference in reflectance between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs).

Tom Logan [JPL], and science team members **Glynn Hulley** [JPL] and **Josh Fisher** [JPL], discussed the scientific basis for and evaluation of ECOSTRESS standard data products, (e.g., radiance, land surface temperature and emissivity, and ET), with preliminary calibration and validation results being shown.

The science team partnered with the LP DAAC for a presentation on ECOSTESS Early Adopters.[6] Over 200 science and applications data users participated in the program, with interests that span topics such as ecosystems, water resources, agriculture, public health (e.g., urban heat-island mapping and vector-borne disease), volcano monitoring, wildfires, geology, and climate, among others.

Afternoon Hands-On Training for Data Use and Visualization

Cole Krehbiel [LP DAAC] and **Gregory Halverson** [NASA/JPL] co-led the afternoon session. They developed the content and materials that comprised the hands-on training package, which highlighted the use of open source software for analyzing ECOSTRESS data, including geospatial analysis in python and visualization and cartography in QGIS.[7] The primary goal of the afternoon session was to help users set up a sample workflow that could later be adapted for their specific investigations.

During the first portion of the workshop, participants were guided through an exercise to find, download, and reproject ECOSTRESS granules into a gridded GeoTIFF[8] format. Converting from ECOSTRESS native swath to a gridded format was requested as a capability by the ECOSTRESS Early Adopters, one that was essential to facilitating downstream data analysis and visualization. The downstream analysis and visualization were covered in the second component of the tutorial. An example of a visualization generated during the meeting

[6] ECOSTRESS is the first NASA Earth Venture mission to have an Early Adopters (EA) program. The title of Early Adopter (EA) is generally given to a select group of users that intend to utilize data from a given mission, who are granted early access to the provisional data (L1–4) as well as opportunities to collaborate with the mission science team. The goal of the ECOSTRESS EA program is to encourage use of and feedback on the provisional data to help improve the quality of the data and understand the extent of their use in research and applied sciences. To learn more about ECOSTRESS Early Adopters, please visit *https://ecostress.jpl.nasa.gov/early-adopters.* As of writing this article, over 250 people have participated in the ECOSTRESS Early Adopters Program, now in transition to becoming the ECOSTRESS Community of Practice with the public release of ECOSTRESS data on June 20, 2019.
[7] Python is an object-oriented computer programming language; QGIS (previously known as Quantum GIS) is a free and open-source, cross-platform, desktop geographic information system (GIS) application that supports viewing, editing, and analyzing geospatial data.
[8] GeoTIFF is a metadata standard in the public domain, embedding georeferenced data in a TIFF image file.

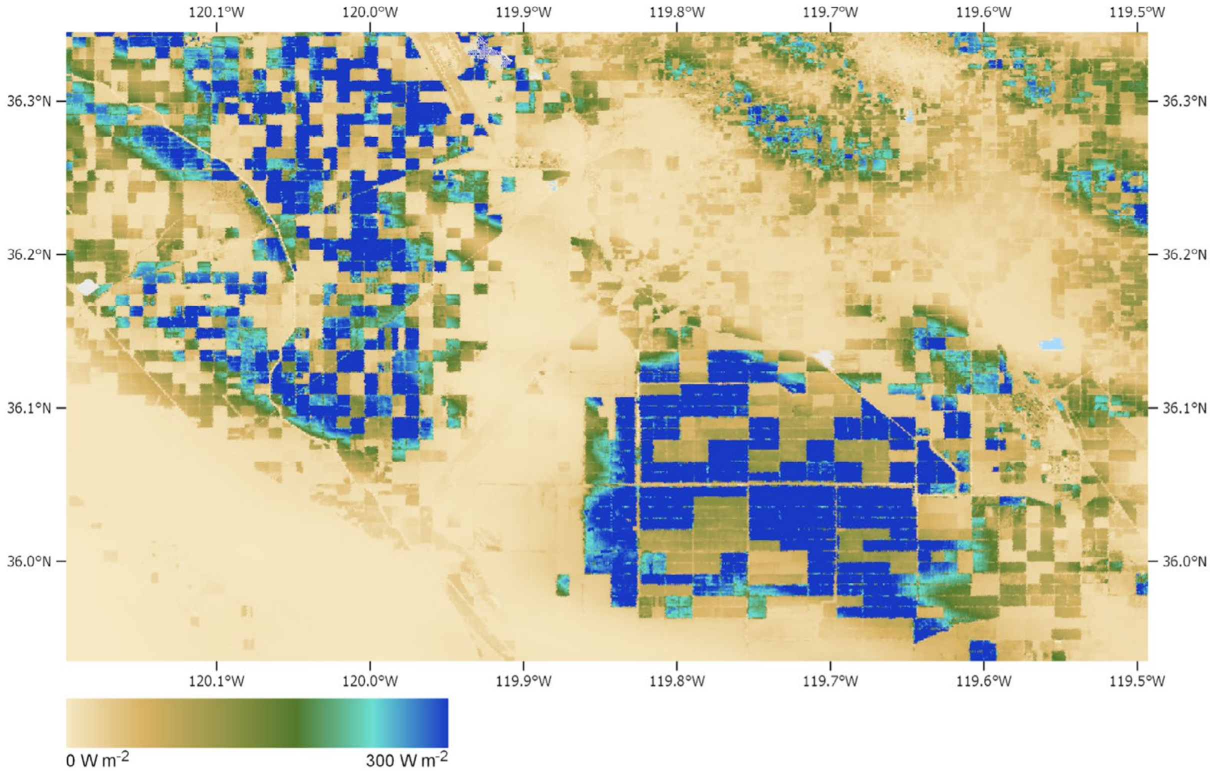

Figure. Evapotranspiration, which is the amount of water being evaporated and transpired over a given area, is expressed here as an energy flux in W/m^2 measured at the moment of ECOSTRESS overpass. This scene was acquired on August 5, 2018 over agricultural areas in Central Valley, CA (40 miles south of Fresno, CA) and produced by a participant at the ECOSTRESS Workshop. **Image credit**: Michael Allen [University of California, Santa Barbara]

is shown in the **Figure** [*above*]; it shows ET data obtained as ECOSTRESS flew over agricultural areas in Central Valley, CA, acquired on August 5, 2018. Participants were encouraged to select a different scene to use in this workshop.

After preparing the data, the team worked with workshop participants to extract and match up ECOSTRESS ET data with FLUXNET[9] tower-derived ET values, display ET time series, and calculate simple statistics [e.g., standard deviation, product uncertainty (which accompanies the L3 ET product), and min/max]. Following this matchup, the team worked through a QGIS exercise to display and customize ECOSTRESS ET product maps, which were then posted on the workshop Slack channel where remote and in-person participants were posting questions about the tutorial and collaborating.

[9] FLUXNET is a global network of micrometeorological tower sites that use eddy covariance methods to measure the exchanges of carbon dioxide, water vapor, and energy between the biosphere and atmosphere. It is a global "network of regional networks" that serves to provide an infrastructure to compile, archive, and distribute data for the scientific community. For more information, visit *https://fluxnet.fluxdata.org/about*.

Conclusion

The ECOSTRESS team was able to prepare and present materials and updates on the mission for the community as well as develop a hands-on workshop, allowing participants to engage in the workshop both in-person and remotely. They were pleased to see the amount of community engagement and interest in ECOSTRESS products—both for the primary science objectives and in topics beyond those emphasized in the proposal. Participants provided positive feedback regarding the information presented during the morning session and the practical utility of the hands-on workshop. It seems clear that ECOSTRESS continues to serve as a key technology implementation for a multiband thermal radiometer and, combined with active community engagement, can provide key lessons learned that feed into future Earth science efforts, such as the *Surface Biology and Geology (SBG) Designated Observable* (as defined in the 2017 Earth Science Decadal Survey—*https://nas-sites.org/americasclimatechoices/2017-2027-decadal-survey-for-earth-science-and-applications-from-space*). SBG, a possible future Earth Science mission, could include global imaging spectroscopy measurements and multispectral (i.e., greater than five-band) thermal measurements. ■

Summary of the 2019 ABoVE Science Team Meeting

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Introduction

The Arctic-Boreal Vulnerability Experiment (ABoVE), organized under the auspices of NASA's Terrestrial Ecology Program, is an approximately ten-year campaign to study environmental and climatic changes in Alaska and northwest Canada and their implications for social and ecological systems. The first scoping study for ABoVE started in 2009, followed by the science definition team writing a concise experiment plan that was completed in 2014; the first ABoVE call for proposals appeared in NASA's Research Opportunities in Space and Earth Sciences (ROSES) 2014 Announcement of Opportunity (AO). Currently, ABoVE is comprised of 66 NASA-funded research projects, and has affiliations with other partner agencies such as the U.S. Department of Energy (DOE), the U.S. National Science Foundation, Natural Resources Canada, POLAR Knowledge Canada (POLAR), and the Natural Sciences and Engineering Research Council of Canada. ABoVE is notionally divided into three phases: Phase I has focused on ecosystem dynamics and encompasses all ABoVE activities up to 2019. Phase II was explicitly launched with the 2019 NASA ROSES AO, which solicited proposals that continued the ecosystem dynamics objectives while also seeking proposals with an emphasis on ecosystem services, societal impacts, and modeling. Phase III, which will focus on analysis and synthesis, notionally begins in 2022. For more information on ABoVE, visit *https://above.nasa.gov*.[1]

[1] To read a summary of the previous ABoVE STM, see "2018 Arctic-Boreal Vulnerability Experiment (ABoVE) Open Science Team Meeting Summary," in the May–June 2018 issue of *The Earth Observer* [**Volume 30, Issue 3,** pp. 28-30—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/May-June%202018%20color%20508.pdf#page=28*].

The ABoVE Science Team held its fifth science team meeting in San Diego, CA, from May 20-23, 2019. There were over 125 attendees from NASA and other U.S. federal agencies, Alaska, and a variety of Canadian federal agencies, Ducks Unlimited Canada, and Déline Got'ine Government (an Indigenous government located in Canada's Northwest Territories), and many representatives from U.S., Canadian, and European universities. Participants from NASA Headquarters (HQ) included **Hank Margolis** [*ABoVE Program Manager*] and **Michael Falkowski** [*ABoVE Program Scientist*]. Support provided by invited-speaker travel funds helped one U.S.-based postdoctoral researcher and five Canadian students, collaborators, and speakers attend the meeting.

Meeting Summary

Peter Griffith [NASA's Goddard Space Flight Center (GSFC)—*Director of the Carbon Cycle & Ecosystems Office*] opened the meeting with a territorial acknowledgement recognizing that the meeting was held on the traditional lands of the Kumeyaay people, who today have numerous reservations in Southern California. He also introduced the meeting code of conduct, as is now required for all NASA conferences and meetings. In general, ABoVE activities are expected to adhere to several codes of conduct*: Principles for Conducting Research in the Arctic* from the Interagency Arctic Research Policy Committee, *Fundamental Principles for the Use of Traditional Knowledge in Strengthening the Work of the Arctic Council,* the *American Geophysical Union Scientific Integrity and Professional Ethics,* and the *American Geoscience Institute Guidelines of Ethical Professional Conduct*. Links to relevant codes of conduct for ABoVE can be found at *https://above.nasa.gov/about.html?#conduct*.

Photo of the 2019 ABoVE Science Team Meeting participants. **Photo credit**: Peter Griffith

Scott Goetz [Northern Arizona University (NAU)—*ABoVE Science Lead*] highlighted the progress to date of Phase I projects, including 135+ publications, 24 of which are available in a special issue of *Environmental Research Letters* (*http://iopscience.iop.org/journal/1748-9326/page/ABoVE*).

Charles "Chip" Miller [NASA/Jet Propulsion Laboratory (JPL)—*ABoVE Deputy Science Lead*] gave an update on results from prior ABoVE Airborne Campaigns and future plans for Summer 2019 flights, including flights of NASA's Land, Vegetation, and Ice Sensor (LVIS), the next-generation, narrow-band Airborne Visual Imaging Infrared Spectrometer (AVIRIS-NG), and L-band synthetic aperture radar (SAR) instruments.

After these opening presentations, participants immersed themselves in the latest ABoVE science results via a series of invited plenary talks, partner presentations, and poster and breakout discussions, the highlights of which are summarized here. Additionally, all newly selected Phase II researchers gave five-minute "speed talks" on their planned ABoVE projects.

All presentations, including breakout session reports, can be downloaded from *https://above.nasa.gov/meeting_2019/agenda_final.html*.

Plenary Sessions

The plenary sessions highlighted some key topics that are relevant to ABoVE. The presentations during the plenary session also set up the breakout session discussions (described on page 22) and framed ABoVE research in a broader context.

Phil Marsh [Wilfred Laurier University] highlighted research by Canadian colleagues on snow in the Western Canadian Arctic. Snow dominates many aspects of the Arctic; winter ecosystem dynamics are changing the most rapidly when compared to the rate of change in other seasons. However, there is a dearth of measurements for many aspects of snow that impedes our understanding of relevant phenomena. He discussed monitoring and modeling activities, and possible future joint activities with NASA's SnowEx campaign.[2]

Kevin Schaefer [National Snow and Ice Data Center] and **Mahta Moghaddam** [University of Southern California] reported on the status of ABoVE radar products from the airborne campaigns of 2017 and 2018. These products provide maps of permafrost active layer thickness and subsidence, biomass, soil moisture, and surface waterbodies.

[2] NASA's SnowEx campaign is a five-year program initiated and funded by NASA's Terrestrial Hydrology Program to address the most important gaps in snow remote sensing knowledge. It focuses on airborne campaigns and field work, and on comparing the various sensing technologies, from the mature to the more experimental, in globally representative types of snow. To learn more, visit *https://snow.nasa.gov/campaigns/snowex*.

Paul Siqueira [University of Massachusetts] gave a presentation on the overlap and shared goals of ABoVE and NISAR,[3] especially as they relate to measurements of biomass and permafrost.

Isla Myers Smith [University of Edinburgh, Scotland] broadened the geographic context of the meeting by presenting a pan-Arctic view of vegetation dynamics. She discussed the possible reasons for disagreement in measurements between different satellite datasets, mechanistic reasons for tundra vegetation change, and ways that ABoVE research can contribute to this research area.

Mandy Bayha and **Joanne Speakman** [from Délı̨ne, Northwest Territories, Canada] gave an Indigenous perspective on environmental and climatic changes in their region, highlighting opportunities for researchers to work together with Indigenous peoples to coproduce knowledge and understanding. They also gave a scintillating recount of their experience flying in a NASA G-III aircraft during a SAR collection, and an associated field data collection excursion in the 2018 field season.[4]

Xanthe Walker [NAU] described the culmination of Phase I research in understanding the impacts of increasing wildfires on soil carbon in forest succession in boreal forests. ABoVE research has found that combustion of soil carbon in wildfires has resulted in substantial carbon sources emitting into the atmosphere. However, the trees that grow back in the aftermath of the fires tend to switch from spruce (conifer) to deciduous trees, which may ultimately result in more carbon being taken out of the atmosphere by the new growing trees.

Joshua Fisher [JPL] summarized the progress in Phase I terrestrial biosphere modeling activities, highlighting the needs identified by the Science Team members—see **Figure** (next page). He discussed the development of a model-data integration framework, which lays the foundation for the modeling activities, connects modeling efforts to field activities early on, and aims to ensure that the data collected meet the needs of the modeling community. He also outlined the plans for Phase II modeling, which involves data-to-model translation, an operational benchmarking system, and structured model development.

[3] NISAR is a compound acronym that stands for NASA–Indian Space Research Organization (ISRO) Synthetic Aperture Radar, a joint NASA–ISRO venture, planned for launch in 2021. To learn more, visit *https://nisar.jpl.nasa.gov*.

[4] Read associated stories at *https://blogs.nasa.gov/earthexpeditions/2018/10/11/students-traverse-land-air-and-water-in-canada-with-nasas-above/* and *https://blogs.nasa.gov/earthexpeditions/2018/10/31/we-are-the-land-and-the-land-is-us-indigenous-women-join-nasas-campaign-to-study-climate-change-in-the-canadian-arctic.*

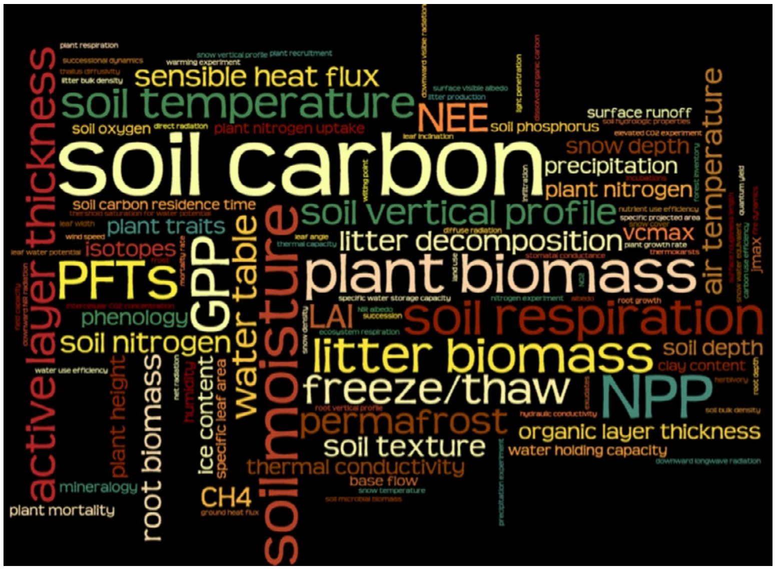


Figure. This word cloud illustrates terrestrial biosphere modeling needs for the Arctic-Boreal Region highlighting soil and vegetation dynamics, as idenfitifed by members of the ABoVE modeling community. The font size of each word or phrase is proportional to the frequency of term mentioned in the responses from 18 modeling groups. **Image credit**: Joshua Fisher [JPL]

Partner Presentations

Partner presentations complemented the plenary talks and breakout-session discussions by providing overviews of potential synergies with other large research programs.

Shawn Serbin [Brookhaven National Laboratory] described the recent work of the DOE's Next Generation Ecosystem Experiment – Arctic (NGEE-Arctic) field campaign in Alaska, highlighting the contribution NGEE-Arctic field and unmanned aerial systems (UAS) data as calibration for ABoVE's airborne data collections, allowing for multiscale analysis of soil moisture, snow, and vegetation properties.

Adam Houben [POLAR] reported on the POLAR activities related to ABoVE, including field research at their Environment and Research Area in Nunavut, Canada, potential future funding for projects via their 2020–2023 competitive funding process, and the logistical assistance they have provided to ABoVE over the years. ABoVE and POLAR recently collaborated on an article describing POLAR's contributions of ABoVE, available at *https://www.canada.ca/content/dam/polar-polaire/documents/pdf/aqhaliat/Aqhaliat-2018-07-Houben-et-al.pdf*.

Jason Edwards [Natural Resources Canada] reported on activities of the Canadian Forest Service, including their development of nation-wide forest change, wildfire burn severity, and wildfire fuels mapping data from satellite imagery, their collaboration with the Government of the Northwest Territories in forest management activities, and their investigation into permafrost and vegetation changes in boreal regions.

Next, the Team heard from representatives from three Canadian universities: **Kevin Turner** [Brock University], **Jennifer Baltzer** [Wilfred Laurier University], and **Merritt Turetsky** [University of Guelph]. Each of them described different research activities of Canadian collaborators in Yukon and/or Northwest Territories that investigate landscape and hydrology changes due to permafrost thaw, vegetation and wildlife changes, wildfire regimes, and carbon cycling.

John Musinsky and **Rommel Zulueta** [National Ecological Observatory Network (NEON)] reported on the status of NEON data and activities in Alaska, including the biological, aquatic, soil, and atmospheric measurements taken both on the ground and via airborne platforms. They described the NEON data portal (*https://data.neonscience.org/home*) and their plans for 2019 airborne data acquisitions.

Applied Sessions

There were lunchtime applied sessions that focused on the ICESat-2[5] and NISAR satellite missions, both of which will provide data that can be used to evaluate vegetation structure and permafrost thaw; new capabilities on the ABoVE Science Cloud; coproduction of knowledge with local and Indigenous communities; and student-mentor matchups. These sessions allowed for both hands-on training and interactions among the science team members.

Poster Sessions

Each afternoon, Science Team members gathered for poster sessions, arranged by science theme. Posters covered the major topics of carbon dynamics, fire disturbance, vegetation dynamics, hydrology and permafrost, wildlife and ecosystem services, and modeling. A detailed poster agenda is available at *https://cce-datasharing.gsfc.nasa.gov/conferences/posteragenda/15/h/0*.

[5] ICESat-2 stands for Ice, Cloud, and land Elevation Satellite-2; it was launched in September 2018, and the team has recently released data to the public. To access data, visit *https://nsidc.org/data/icesat-2/data-sets*.

Table. ABoVE Science Team interdisciplinary working groups and chairpersons.

Working Group	Chair(s) [Affiliation(s)]
Hydrology & Permafrost	**John Kimball** [University of Montana] **David Butman** [University of Washington]
Vegetation Dynamics & Distribution	**Howard Epstein** [University of Virginia] **Brendan Rogers** [Woods Hole Research Center]
Vegetation Structure & Function	**Paul Montesano** [NASA's Goddard Space Flight Center]
Fire & Insect Disturbance	**Laura Bourgeau-Chavez** [Michigan Technological University] **Tatiana Loboda** [University of Maryland]
Carbon Dynamics	**Abhishek Chatterjee** [NASA's Goddard Space Flight Center] **Colm Sweeney** [NOAA's Earth System Research Laboratory]
Ecosystem Services & Co-Production	**Todd Brinkman** [University of Alaska, Fairbanks] **David Lutz** [Dartmouth College]
Snowscapes	**Natalie Boelman** [Lamont–Doherty Earth Observatory/Columbia University] **Laura Prugh** [University of Washington]
Modeling	**Joshua Fisher** [NASA/Jet Propulsion Laboratory]

Breakout Sessions

A key aspect of the Science Team Meeting was the opportunity for the ABoVE interdisciplinary working groups to meet both individually and across topic areas to advance ongoing synthesis activities, identify knowledge gaps, and discuss potential new synthesis activities. Each day allowed for ample time for such discussions during the breakout sessions, with groups reporting back to the larger group the next day. For a list of the primary science ABoVE working group leads, see the **Table**. For a full list of all working groups, visit *https://above.nasa.gov/cgi-bin/above_wg.pl*.

ORNL DAAC Presents Awards to ABoVE STM Members

During the ABoVE Science Team Meeting, **Jack McNelis** [Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC)] presented three awards to ABoVE scientists including: **Logan Berner** [NAU] who received the *DAAC Staff Favorite* award; **Mark Carroll** [GSFC] who received the *Outstanding Representation in the Literature* award; and **Tatiana Loboda** [University of Maryland, College Park] who received the *Most Downloaded Dataset* award.

Conclusion

It is clear that ABoVE continues to be innovative, productive, and impactful, with more than 135 publications to-date, including several in top-tier journals such as *Nature*, *Science*, and *Proceedings of the National Academy of Sciences*. ABoVE also continues to broaden its impact via increased sharing of datasets through the ORNL DAAC. Currently there are 80 ABoVE data products stored at the ORNL DAAC with 2700 unique users of ABoVE datasets.

The Science Team Meeting provided an opportunity for newly selected projects to introduce their work and learn about the ABoVE successes to date. During the plenary sessions team members learned about the data products resulting from ongoing airborne campaigns, emerging scientific understanding and research needs, environmental and climatic change in the broader, pan-Arctic context, and the ongoing activities of ABoVE's state, national, and international partners. The applied sessions had more in-depth exploration of technical issues, approaches, and tools used by ABoVE researchers. The breakout sessions enabled thematic teams to discuss current and ongoing collaborations, with additional time provided from cross-thematic discussions. Poster sessions allowed for the opportunity for individual projects to share scientific details of their ongoing work. The variety of activities and opportunities for both formal and informal interactions kept the meeting lively and engaging.

The next ABoVE Science Team Meeting is scheduled for May 11-14, 2020, in Fairbanks, AK. Keep an eye on *https://go.nasa.gov/2WFg2FJ* for future information. ■

Summary of the Thirty-First CERES Science Team Meeting

Walter Miller, NASA's Langley Research Center, Science Systems and Applications, Inc., walter.f.miller@nasa.gov

Introduction

The thirty-first Clouds and the Earth's Radiant Energy System (CERES) Science Team Meeting (STM) was held May 7-9, 2019, at NASA's Langley Research Center (LaRC) in Hampton, VA. **Norman Loeb** [LaRC—*CERES Principal Investigator*] hosted and conducted the meeting.

The meeting agenda listing speakers and their presentations is available online at *https://ceres.larc.nasa.gov/science-team-meetings2.php?date=2019-05*. Selected highlights from the presentations given at the meeting are summarized in this article. In the text that follows, there are references to some specific presentations where more information can be found on topics briefly mentioned in the summary.

Programmatic and Technical Presentations

Norman Loeb outlined the major objectives of the CERES STM, which were to:

- review the performance and calibration of all CERES instruments[1]—he reported that there has been no change in their health and that calibrations remain consistent;
- discuss the release of the Terra and Aqua Edition 4.1 versions of the merged Level 3 products;
- provide an overview of the Suomi National Polar-orbiting Partnership (NPP) Edition 2 plans;
- demonstrate the progress on Terra and Aqua Edition 5 development; and
- discuss CERES data product validation.

Loeb discussed the CERES merged product suite. The Energy Balanced and Filled (EBAF) and Synoptic 1 degree (SYN1deg) products, which use information from both Earth Observing System (EOS) (i.e., Aqua and Terra) and geostationary satellites (i.e. GOES 16,[2] Himawari 8,[3] METEOSAT 8,[4] METEOSAT 10, and METEOSAT 11) have been reprocessed. The major changes are that the new products use aerosol data from Collection 6.1 of the Moderate Resolution Imaging Spectroradiometer (MODIS)[5] data for the entire record; they also use updated CERES Single Scanner Footprint (SSF) data after February 2016 (see *Fall 2018 CERES STM* for details),[6] and updated geostationary imager data for dates after June 2015.

Loeb noted that the aerosol optical depth values from MODIS Collection 6.1 are less over land than had previously been seen in Collection 5 resulting in less shortwave (SW) flux reaching the surface—see **Seiji Kato**'s [LaRC] presentation from the current meeting for details. As part of releasing the new Edition 4.1 EBAF, the top-of-atmosphere (TOA) product—which saw no changes to the TOA fluxes—will continue to be released.

Loeb also reported that a new EBAF product has just been released, which contains both the original TOA fluxes and surface fluxes with the addition of TOA and surface SW, longwave (LW) fluxes, and net clear-sky flux for the total region being added—see **Norm Loeb**'s second presentation from the current meeting for details. This new flux estimate adjusts the observed monthly mean clear-sky flux values using the difference between a calculated value from a radiative transfer model that has removed the clouds from the atmospheric profile and the calculated value for the clear-sky flux weighted by the clear area—which is more representative of how clear-sky flux is calculated from climate model fields. **Figure 1** on page 24 shows how the *average* (which is based on mean values between 2003 and 2014) of the more consistent Longwave TOA Cloud Radiative Effect (CRE) from EBAF has less differences when compared with the multimodel means from Coupled Model Intercomparison Project Phase 6 (CMIP6)[7] over the same period than the previously provided values. The CRE is now calculated using the new clear-sky fluxes.

[1] There are currently six CERES instruments active on four satellites: two on Terra [Flight Model (FM)-1 and -2]; two on Aqua [FM-3 and -4]; one on the Suomi National Polar-orbiting Partnership (NPP) [FM-5]; and one on the National Oceanic and Atmospheric Administration's NOAA-20 satellite [FM-6].
[2] GOES stands for the Geostationary Operational Environmental Satellite, a series of satellites operated by NOAA.
[3] Himawari is the Japanese Meteorological Agency's line of geostationary satellites.
[4] Four Meteosat Second-Generation (MSG) satellites (MSG-1, -2, -3, and -4) have been launched, the most recent in 2015. MSG-1, -2, -3, and -4 have been renamed Meteosat-8, -9, -10, and -11, respectively.

[5] Like CERES, MODIS instruments fly on NASA's Terra and Aqua platforms.
[6] References to Fall *2018 CERES STM* throughout the article refer to "Summary of the Thirtieth CERES Science Team Meeting and the 2018 Earth Radiatiion Budget Workshop" in the November–December 2018 issue of *The Earth Obsever* [**Volume 30**, **Issue 6**, pp. 35-37—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Nov_Dec_2018_color508_0.pdf#page=35*].
[7] CMIP is a standard experimental framework for studying the output of coupled atmosphere-ocean general circulation models, allowing for an assesement of model strengths and weaknesses, and contributing to the development of future models. CMIP6 is the most recent of these assessments. Learn more at *https://www.wcrp-climate.org/wgcm-cmip*.

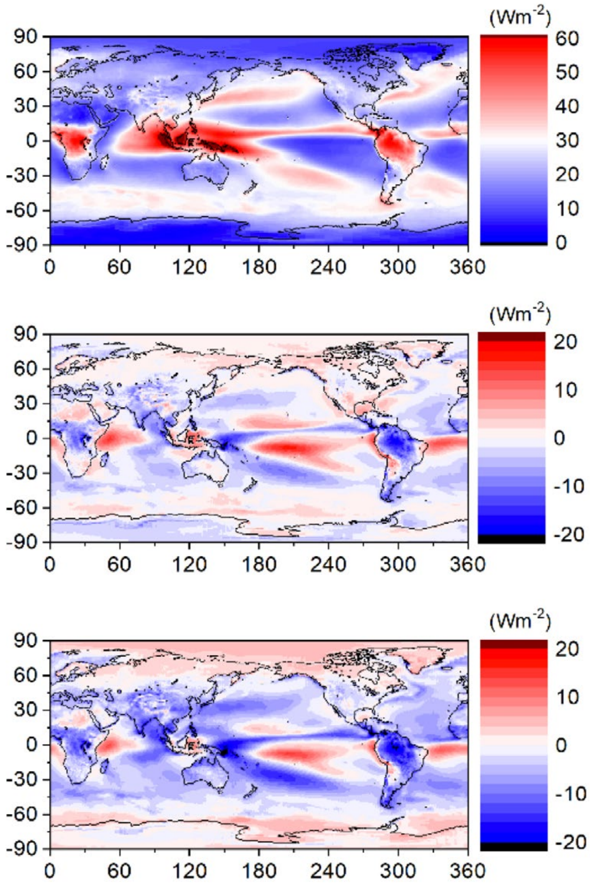


Figure 1. The new Longwave (LW) top of atmosphere (TOA) Cloud Radiative Effect (CRE) with adjustment in the CERES Energy Balanced and Filled (EBAF) product for 2003 through 2014 [*top*], the difference between the seven CMIP6 multimodel mean LW TOA CRE and the EBAF-TOA LW CRE variable with adjustment that has a root mean square difference of 4.5 W/m^2 [*middle*], and the difference between the CMIP6 multimodel mean LW TOA CRE and the earlier EBAF-TOA LW CRE variable without adjustment that has a root mean square difference of 6.1 W/m^2. See page 23 of text for further explanation of these images and expansions of acronyms not expanded in caption. **Image credit**: Norman Loeb

David Considine [NASA Headquarters (HQ)] spoke about the Earth Venture-Continuity-1 (EVC–1) mission, which is a low-cost, cost-capped mission being used to extend current NASA Earth Radiation Budget climate data records. The program is in response to the 2017 Decadal Survey's recommendation to continue the Program of Record for key observations—but to find ways to do it more efficiently. Instrument proposals from the Announcement of Opportunity (AO) are due July 26, 2019.[8] Considine reviewed the various steps in the evaluation process and the criteria that will be used to judge the proposals. He also assured participants the two criteria related to science merit are more-significant factors in the decision than the technical-, management-, and cost-portion evaluations.

[8] The 2017 Earth Science Decadal Survey, "Thriving on a Changing Planet: A Decadal Strategy for Earth Observation from Space," can be viewed at and downloaded from *https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth*.

Invited Science Presentations

The members of the modeling community are primary users of CERES radiation and flux data for validating and analyzing their models. Two modelers provided invited presentations on the second day.

Yi Huang [McGill University, Canada] shared his research on radiation variability in regional climate. His study focused on the ability to describe a balanced radiation budget through both observations and general circulation model (GCM) simulations. Noting that most GCMs have too strong a positive cloud feedback (especially in the central-east Pacific), Huang created a new set of radiative kernels that relates changes in water vapor or temperature to changes in the net radiative flux. These kernels are then applied both to the surface and vertically integrated values of temperature and water vapor. Huang has applied his kernel to many CMIP5 models, with results that consistently show high net TOA flux over the central Pacific. The source of the anomaly is cloud feedback at the surface with no compensation between LW and SW, causing significant cooling of sea surface temperature (SST), but warming in the atmosphere above, which sets up an anomalous circulation. A strong correlation between change in tropical circulation strength and radiative differential heating is also observed in the CMIP5 models.

Huang also studied the cloud feedback associated with Arctic sea ice change. There is currently no consensus on feedback direction in the Arctic, especially since the record length continues to increase. He noted that the kernels may fail in the Arctic because the kernels used in his tropical analysis are developed based on the assumption of small changes from current values, but the Arctic presents large albedo changes between sea ice and open ocean. To address this failure, Huang has developed an alternative neural net method to relate the atmospheric state to the radiative flux. The neural net produced a much better radiation closure than the kernel.

Joel Norris [Scripps Institution of Oceanography (SIO)] explained that clouds remain one of the greatest sources of uncertainty in climate models, and that climate sensitivity can range from strongly positive to moderately negative, depending on the model. He investigated how using GCM data and observed cloud and radiation values can narrow the range of climate sensitivity caused by clouds. GCMs explicitly calculate changes in meteorological parameters (e.g., temperature, winds, humidity), whereas, in the model, observed cloud and radiation properties are *parameterized* (determined by algorithms based on the meteorological variables). While the changes in meteorological parameters caused by increased atmospheric carbon dioxide (CO_2) generally have shown good agreement between GCMs, cloud response to increased CO_2 varies widely. The different representation of clouds in GCMs results in different cloud feedback impacts to the radiation budget, leading to the large variations in derived climate sensitivities.

To address this, Norris developed a method to determine how low cloud amounts come from changes in observed variables like SST. The initial model cloud field can be adjusted using the model's change in SST. Norris earlier conducted a study in which he looked at low-latitude ocean grid boxes, where subsidence always occurs. (Physically this corresponds to stratocumulus fields off the west coast of continents.) By applying the above technique, he found the amount of cloud feedback is moderately positive—and more consistent between GCMs.

Norris has expanded his earlier work to include the effects of upper-level clouds on low-level clouds, and includes all types of low-level cloud regimes, e.g., trade cumulus, deep convection, mid-latitude, and those associated with the southeastern Pacific cold tongue off the coast of Peru. The new study, described above, shows four times the current levels of atmospheric CO_2 scenario as previous studies, confirming the positive cloud feedback in stratocumulus regions, but reducing its magnitude. However, trade cumulus, midlatitude, and southeastern Pacific cold-tongue cloud regimes have negative feedbacks. When the coverage of the various regimes is accounted for, the global low-level cloud feedback is near zero, although the statistical uncertainty allows for either a small positive or negative feedback.

Contributed Science Presentations

This section of the meeting contained seventeen presentations that addressed:

- various input or validation data sources used by CERES;
- the status of algorithm development or understanding limitations of current algorithms; and
- validation efforts from field campaigns and independent measurements.

Two of these presentations addressed topics not discussed at previous CERES STMs that have interest in the wider scientific community, and are thus highlighted below. All the others can be found at the URL referenced in the Introduction.

Ryan Scott [SIO] provided insight into how changes in the energy budget, meteorological conditions, and large-scale climate forcing has increased the West Antarctic Ice Sheet (WAIS) surface-ice melt since the mid-1990s. Scott showed that the rate of mass loss in this area has tripled in the last decade, from about 1000 to 3000 gigatons a year. While this loss is primarily driven by warm seawater thinning the coastal ice shelves, satellite microwave records reveal that there have also been extensive surface melt events. During the Atmosphere Radiation Measurement (ARM) West Antarctic Radiation Experiment [AWARE], the ARM "Extended Facility"[9] deployed for 45 days, from December 2015 to January 2016, which allowed capturing the first measurements in West Antarctica during a melt event. During this period, a strong ice-falling moisture plume entered the region from the north, which significantly increased the downwelling LW radiation from an average of 170 W/m^2 prior to the event, to 300 W/m^2 during it. Since there was little change in the SW absorption throughout the campaign, the result was a net radiative heating of the snowpack and melting ice. Scott then related this single event to overall trends in the Antarctic. Despite an overall trend for the Antarctic Peninsula toward cooling and sea-ice expansion since the turn of the century, surface-ice melt has increased over the WAIS during the same period. A change in wind patterns has increased advection of marine air, thereby resulting in more surface heating.

J. Brant Dodson [Science Systems and Applications, Inc. (SSAI)/LaRC] introduced a test program being run by the Global Learning and Observations to Benefit the Environment (GLOBE) program. CERES has had a program that lets students make cloud observations to compare with satellite cloud detections for over 20 years, initially through CERES Students' Cloud Observation On-Line (S'COOL) program and, since January 2017, through GLOBE. The test program is extending these observations to include whether contrails—which have a small, but significant effect on Earth's radiation budget—are present or not. Unfortunately, current contrail observations are limited due to the difficulty of spotting them from space or even from the aircraft itself. However, they usually stand out when seen from the ground, making such observations ideal candidates to add to the increasing database of student- and citizen scientist-made, ground-based observations. The type of aircraft—and more specifically the nature of its engines—and if it is flying in a moist layer are key variables that play a role in whether or not contrails will occur. Dodson also described and demonstrated the *Flightradar24* app that is available for both iOS and Android, which has been developed to handle the challenge of determining that an aircraft is flying when contrails are not visible. The app provides information on aircraft type, calibrated altitude, and heading. *Flightradar24* additionally has an augmented reality function such that when users point their phones to the

[9] The WAIS Divide Extended Facility housed broadband SKYRAD and GNDRAD radiometer systems, surface energy balance system (SEBS), multifrequency rotating shadow-band radiometer (MFRSR), Cimel Systems sun-tracking photometer (CPSHOT), and surface meteorology (MET). Additionally, a micropulse lidar (MPL), ceilometer, and G-band vertical radiometer profiling system (GVRP) had been set up in the vicinity.

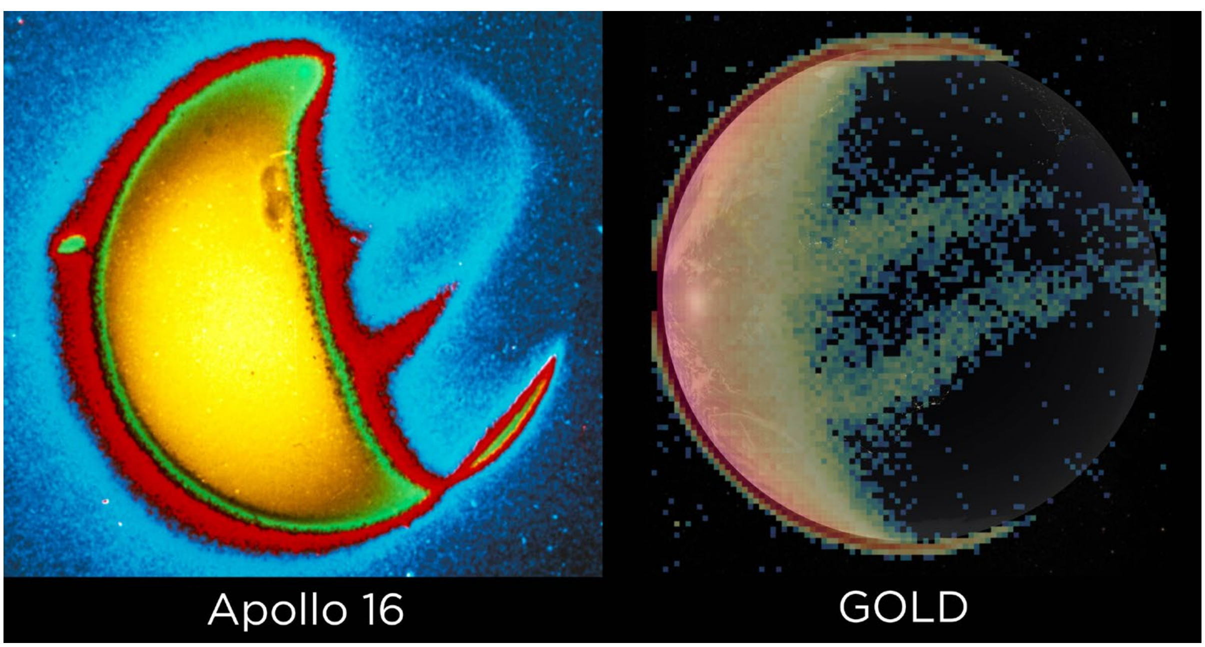
Figure 2. The augmented reality view of the *Flightradar24* app when pointed to the sky. The black circle highlights a contrail and boxes provide flight information of various aircraft being viewed. **Image credit**: Brant Dodson

sky, the app will identify where the aircraft are, as well as other details on the aircraft—as shown in **Figure 2**.

Conclusion

This was yet another successful CERES STM meeting. The invited speakers gave insight into how the CERES products are valuable to the modeling community, and several providers of data used in CERES products described their efforts to improve the products. The CERES team highlighted changes from reprocessing of their merged Level 3 products, including announcing the new EBAF product. Other presentations covered results from the team's efforts in validating the current CERES data products and efforts toward preparing for the next edition of products.

The next CERES STM will be held October 29-31, 2019, at Lawrence Berkeley National Laboratory, Berkeley, CA. ■



July 20, 2019 marked the fiftieth anniversary of the Apollo 11 Moon landing. This was the first of six Apollo missions that successfully landed humans on the Moon between 1969 and 1972. (Apollo 13 was unable to land on the Moon.) The image pair shown here compares two views of Earth's shining ionosphere: one a photograph from the Far Ultraviolet Camera taken by Apollo 16 Astronauts John Young and Charles Duke in 1972, during the penultimate Apollo mission [*left*], and the other a visualization derived from observations obtained by NASA's Global-scale Observations of the Limb and Disk (GOLD) during March 2019 [*right*]. The perspectives differ slightly because while the Apollo photo was taken from the Moon's surface, GOLD images Earth's ionosphere from geostationary orbit. **Image credits:** *Apollo image*: George Carruthers [Naval Research Laboratory] et al./Far UV Camera/NASA/Apollo 16; *GOLD image*: NASA/GOLD/Tom Bridgman and Joy Ng [both at NASA's Scientific Visualization Studio]

When Drought Threatens Crops: NASA's Role in Famine Warnings

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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.

NASA's satellite imagery and model forecasts regularly help agricultural and aid agencies to monitor the performance of crops worldwide and prepare for food shortages. **Photo credit**: USDA/FAS/Curt Reynolds

NASA's satellite imagery and model forecasts regularly help agricultural and aid agencies to monitor the performance of crops worldwide and prepare for food shortages.

"In the 1970s the U.S. realized that drought impacts on global agriculture were severely affecting trade and food aid decisions, while ground-based information and forecasting of drought was very limited," said **Brad Doorn** [NASA Headquarters—*Water Resources Program Manager* for the *Earth Science Division*]. "Earth observations from space provide the persistent, global information needed to detect precipitation, temperature, soil moisture, and vegetation conditions that give us a more complete picture of conditions that lead to drought, as well as its impacts."

One of the areas of the planet that NASA and its partner agencies have been keeping a close eye on is Southern Africa, which has experienced a year of extremes. Overly dry conditions developed across parts of the region around the start of the 2018–2019 maize crop season in October and persist until today, putting millions of people at risk of famine.[1] Countries like Namibia, Zimbabwe, and Angola are facing some of the worst droughts on record—see photo above. To make matters worse, two tropical cyclones hit areas of Mozambique and surrounding regions in March and April, causing flooding and high levels of crop loss in the affected region.

The drought is tied to El Niño, a weather pattern that generates persistent warming in the central and eastern tropical Pacific, which is expected to last until the end of 2019. El Niño brings high temperatures and a dearth of rainfall to Southern Africa. When the shortages in rainfall persist, they evolve into deficits in soil moisture, which can decimate rainfed crops—the most predominant type in Southern Africa, where less than 10% of the arable land is irrigated.

Each of the steps leading to agricultural drought can be seen from space. As drought conditions develop, NASA computer models that use satellite measurements provide an outlook for the upcoming months.

Measuring Moisture

A team at NASA's Goddard Space Flight Center (GSFC) has developed a data assimilation system that takes observations from NASA's Soil Moisture Active

[1] To view an animation that shows the progression of the drought in Southern Africa from October 2018 to May 2019, visit *https://www.nasa.gov/sites/default/files/thumbnails/image/soildrought.gif*.

Passive (SMAP) satellite and ingests them into the U.S. Department of Agriculture's Foreign Agricultural Service (FAS) crop forecasting system, which is used by the agency to monitor regional droughts and floods and forecast crop yield. SMAP, launched in 2015, measures the water content of soils and can give a first warning on crop stress.

"The FAS crop analysts use the enhanced soil moisture information we provide them to predict the impact of drought on crop growth and estimate expected end-of-season yield. Crop-yield forecasts are updated monthly and are presented relative to last year's yield and last month's estimates," said **Iliana Mladenova** [GSFC].

The FAS's soil moisture model also incorporates precipitation and temperature observations to derive soil moisture. But there are areas of the world where rain gauges are scarce or don't get properly maintained, like Southern Africa. Direct satellite measurements of soil moisture in these places may be used to correct the model for precipitation errors and improve the model estimates of the soil water content at the surface and the root zone—the soil region where plants extract water from.

NASA's Applied Sciences Program has been collaborating with FAS since 2005. Back then, the soil moisture measurements came from NASA's Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E) satellite mission (which flies on NASA's Aqua platform but is no longer functional). Mladenova expects to eventually be able to combine the measurements from different satellite missions into a "soil moisture almanac" of sorts.

Famine Early Warnings

NASA is also part of an interagency effort funded by the United States Agency for International Development (USAID) that provides early warning and analysis on instances of acute food insecurity around the world. NASA contributes to the Famine Early Warning System Network (FEWS NET), by running seasonal forecasting models to predict the evolution of temperature and precipitation, as well as other hydrological variables, for up to half a year in advance.[2]

"FEWS NET's mission is to inform the U.S. where we might need to send aid," said **Christa Peters-Lidard** [GSFC—*Deputy Director for Hydrosphere, Biosphere, and Geophysics]*. "If a country is in a situation where they are unable to mitigate the drought because they don't have the ability to irrigate or have access to alternative food markets, that's where the U.S. and our partners across the world have to make decisions about whether to send aid."

NASA has been involved in FEWS NET since its launch in 1985. This longstanding collaboration has evolved from one focused primarily on remote sensing of vegetation conditions to one that takes advantage of NASA's Land Information System, a software framework that integrates satellite and ground-based observations with models.

NASA's efforts to monitor agricultural drought will only become more important in the future, with droughts expected to become more frequent and intense as the climate warms.

"There is a lot of uncertainty about what the future holds for Southern Africa with respect to rainfall, but there is observational evidence that air temperatures are increasing across the region," said **Amy McNally** [GSFC/University of Maryland, College Park]. "Higher temperatures are associated with greater aridity meaning more evaporation from reservoirs and drier soils." ■

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[2] To learn more about another early warning system in which NASA is a partner, see "Increasing Information Access for Food Security Monitoring: Overview of the GEOGLAM Crop Monitor for Early Warning (CM4EW)" in the May–June issue of *The Earth Observer* [**Volume 31**, **Issue 3**, pp. 4-14—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/May_Jun_2019_color.pdf#page=4*]. **Note**: GEOGLAM stands for Group on Earth Observations Global Agriculture Monitoring Initiative.

NASA Helps Warn of Harmful Algal Blooms in Lakes, Reservoirs

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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.

Harmful algal blooms (HABs) can cause big problems in coastal areas and lakes across the U.S. When toxin-containing aquatic organisms multiply and form a bloom, it can sicken people and pets, contaminate drinking water, and force closures at boating and swimming sites.

With limited resources to monitor these often-unpredictable blooms, water managers are turning to new technologies from NASA and its partners to detect and keep track of potential hazards. This is particularly critical in lakes and reservoirs that people use for both recreation and water supply.

A new app for Android mobile devices, from the U.S. Environmental Protection Agency (EPA) and now available on Google Play, will alert officials and members of the public when an HAB could be forming, depending on specific changes in the color of the water observed by satellites. The app is a product of the multiagency Cyanobacteria Assessment Network, or CyAN.[1]

"The interest is to use remote sensing as an eye-in-the-sky, early warning system to get a picture of harmful cyanobacteria in U.S. inland lakes," said **Jeremy Werdell** [NASA's Goddard Space Flight Center (GSFC)—*NASA CyAN Lead*].

"Resources are limited, and it's not possible for everyone on the ground to be monitoring all inland water bodies all of the time," Werdell added. "Satellites are providing a tool to help inform how and when to expend resources to go and collect water samples."

NASA has been studying water quality from space for decades, beginning in 1978 with the Coastal Zone Color Scanner that used the color of the ocean to study phytoplankton populations. With later instruments, like the Moderate Resolution Imaging Spectroradiometer on NASA's Terra and Aqua satellites, the resolution was fine enough to distinguish larger inland lakes and reservoirs, and scientists began to use the data to detect the signatures of cyanobacteria in fresh water.

Cyanobacteria occur naturally in many bodies of water, from the Great Lakes to small neighborhood ponds. In small numbers, these algae are not a problem. But under the right conditions—warm water, sunlight, and nutrients that often wash off agricultural fields—cyanobacteria can multiply and form potentially toxic blooms.

Even though the individual algae are microscopic, blooms can be seen from space. In massive numbers, cyanobacteria blooms can appear as large green swaths and patches due to the organisms' main photosynthetic pigment. Their presence can also be detected using fluorescence, which algal blooms emit in response to exposure to sunlight. Using the blooms' unique characteristics, instruments on the NASA/U.S. Geological Survey Landsat satellites, the European Space Agency's Copernicus Sentinel-2 and Copernicus Sentinel-3 satellites, as well as several others, are able to pinpoint the presence of algae.

With computer programs developed to crunch those satellite observations from Sentinel-3, NASA supercomputers produce weekly reports on the color—and other water quality information—of more than 2000 lakes across the United States as part of the CyAN project, said **Bridget Seegers** [GSFC].

Users of the new CyAN app will be able to mark a particular lake with a pin—which will appear as green if the lake appears bloom free, yellow if algae are present but below a certain threshold of concern, or red, indicating that a bloom is likely present. It's designed not only for water-quality managers, Seegers said, but also for people putting canoes on their cars and debating where to go, or outfitters directing people to the best lake for kayaking.

CyAN started in 2015, and has worked with state and local agencies to identify potentially harmful blooms, said **Blake Schaeffer** [Environmental Protection Agency (EPA)—*EPA CyAN Lead*].

Water quality managers with EPA's Regional Offices and its Office of Water teamed up with CyAN to test and evaluate the app and satellite data, he said. Furthermore, citizen scientist groups, tribal groups and the public have also shown interest in the data.

"We're putting the power of the satellite information directly into the hands of the people," Schaeffer said. "They don't have to mine for data; they can opt to have the data pushed to them."

The program does have limitations, however. The satellites can't see through clouds, and because of the resolution of Sentinel-3A, lakes would need to be a bit more than half a mile (900 m) wide to track with the highest-quality data.

[1] CyAN is a partnership between NASA, the EPA, the U.S. Geological Survey (USGS), and the National Oceanic and Atmospheric Administration (NOAA).

To peer at even smaller lakes and reservoirs, Schaeffer and others are turning to Landsat—see **Figure**. Because of issues with clouds (and a less frequent revisit) with the Landsat satellites, scientists get about one clear measurement of a given site every month. But with Landsat's higher spatial resolution, they can track water quality information from more than 60% of the lakes and reservoirs in the U.S.—which is more than 170,000 bodies of water.

Landsat and Sentinel-3 are complementary; Landsat has greater spatial resolution whereas Sentinel-3 gathers data over individual sites more frequently and detects wavelengths more appropriate for cyanobacteria. In addition, Landsat satellites have thermal sensors that can be used to monitor the surface temperature of lakes—important information, as warmer temperatures promote bloom growth. Schaeffer is investigating how to add that additional factor into the monitoring program.

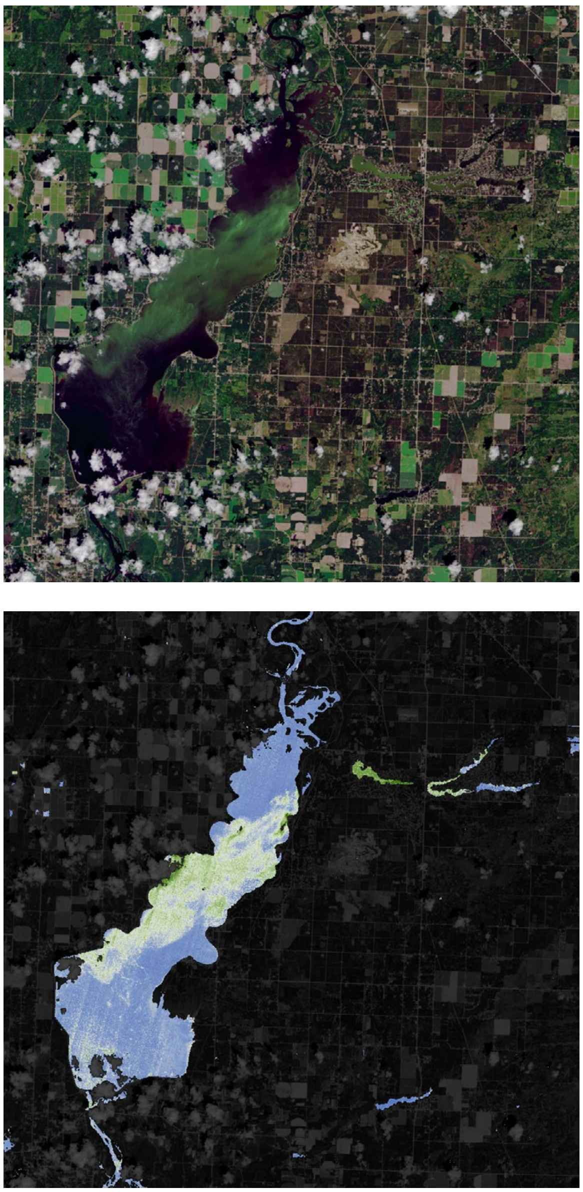


Figure. Scientists analyze high-resolution land images like the top image shown here, which was obtained on August 18, 2018, by Landsat 8's Operational Land Imager (OLI) as it passed over Wisconsin, to detect high concentrations of chlorophyll-a (indicated by darker shades in the bottom image), which can warn water managers of potential harmful algal blooms. **Image credit**: NASA's Earth Observatory/Joshua Stevens—see *https://earthobservatory.nasa.gov/images/145209/nasa-helps-warn-of-harmful-algae-in-lakes-reservoirs*.

Ultimately, the goal is to create a water quality monitoring system that leverages data from many sources—e.g., Sentinel-2, Landsat, and other satellites, as well as information gathered in situ, on the water, said **Nima Pahlevan** [GSFC—*Landsat Science Team Member]*.

Pahlevan and his team are working on how best to use Landsat and Sentinel data to identify lakes, rivers, reservoirs, and other water bodies with excessive algae present. The Landsat Project has been operating since the late 1970s, so researchers and water managers can track the history of a given lake to determine if each lake—or potentially even an individual pixel within an image of a lake—has changed, and if it indicates a bloom.

"We're hoping that with these images, produced in near-real time—within as little as three-to-four hours—we can build a system to issue warnings that are specific to each lake or reservoir," Pahlevan said.

One challenge the group is facing is that there aren't many water measurements being taken across the different lakes to compare with, and verify, what the satellite is reporting. With support from the Landsat Project Science Office, Pahlevan and collaborators have placed three instruments in Green Bay, WI, Lake Okeechobee, FL, and Grizzly Bay, CA, to take measurements of the water for comparison with measurements from Landsat and other satellites.

With those data from the field, and work this summer that includes tracking a handful of lakes using Landsat and Sentinel-2, Pahlevan hopes to build up the program and expand it to an operational system with more locations by summer 2020.

For people like **Donalea Dinsmore** [Wisconsin Department of Natural Resources (DNR)], more satellite monitoring tools would be a welcome addition to the suite of methods the state uses to keep track of where and when harmful algal blooms occur. Each summer, the department receives questions about whether the green muck floating on lakes is harmful. It even fields reports of dogs sickened after swimming in or drinking from a lake, she said. Wisconsin's DNR staff monitor many of the thousands of lakes in the state, but they can't reach everywhere.

"With 15,000 lakes, can you visit them all? And depending on when you visit, you might just miss a bloom," Dinsmore said. "It can be a really complicated and expensive monitoring program if you go in blind." ■

NASA's ECOSTRESS Maps European Heat Wave from Space

Esprit Smith, NASA/Jet Propulsion Laboratory, esprit.smith@jpl.nasa.gov

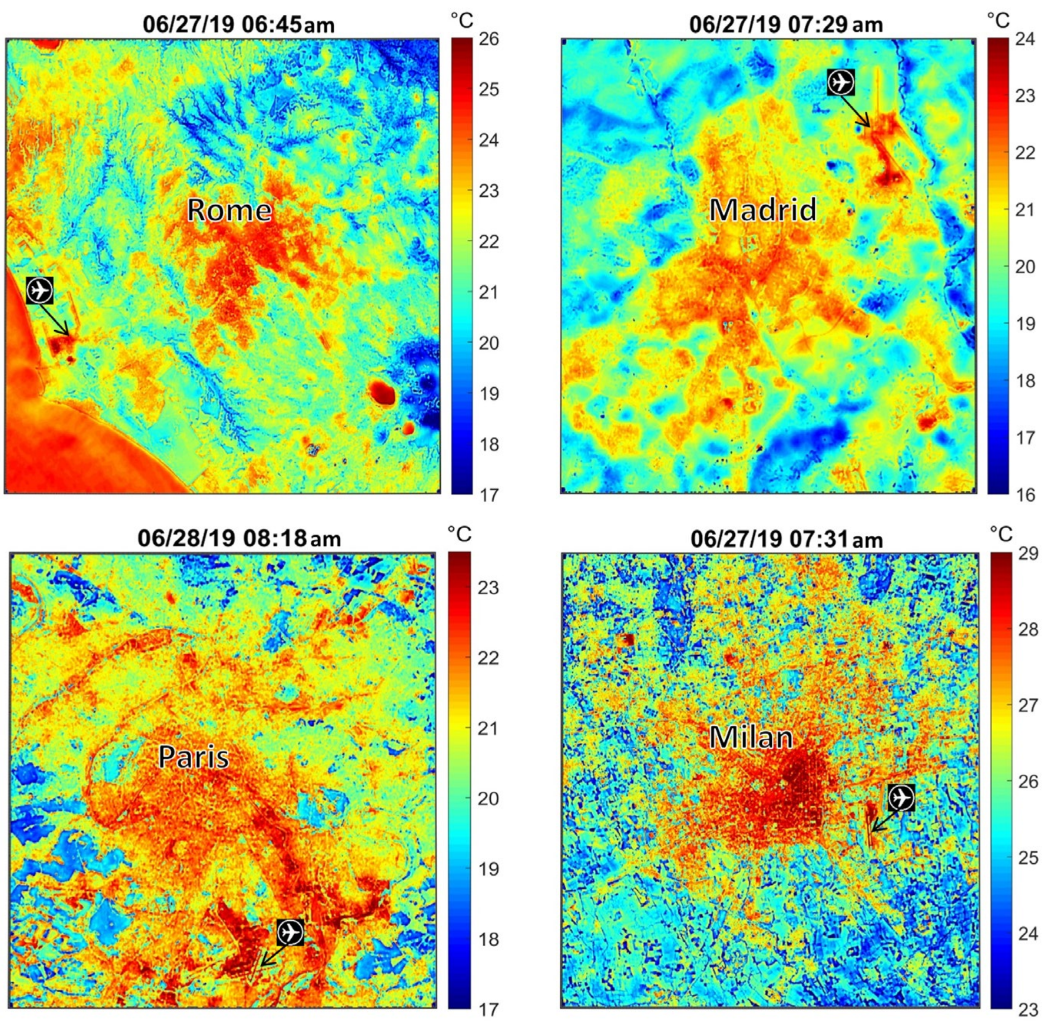
EDITOR'S NOTE: This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

Europe's recent massive heat wave left a slew of broken temperature records in its wake. Many countries were gripped by temperatures above 104 °F (40 °C) between June 26 and June 30, 2019. According to the World Meteorological Organization, June 2019 is now the hottest month on record for the European continent as a whole.

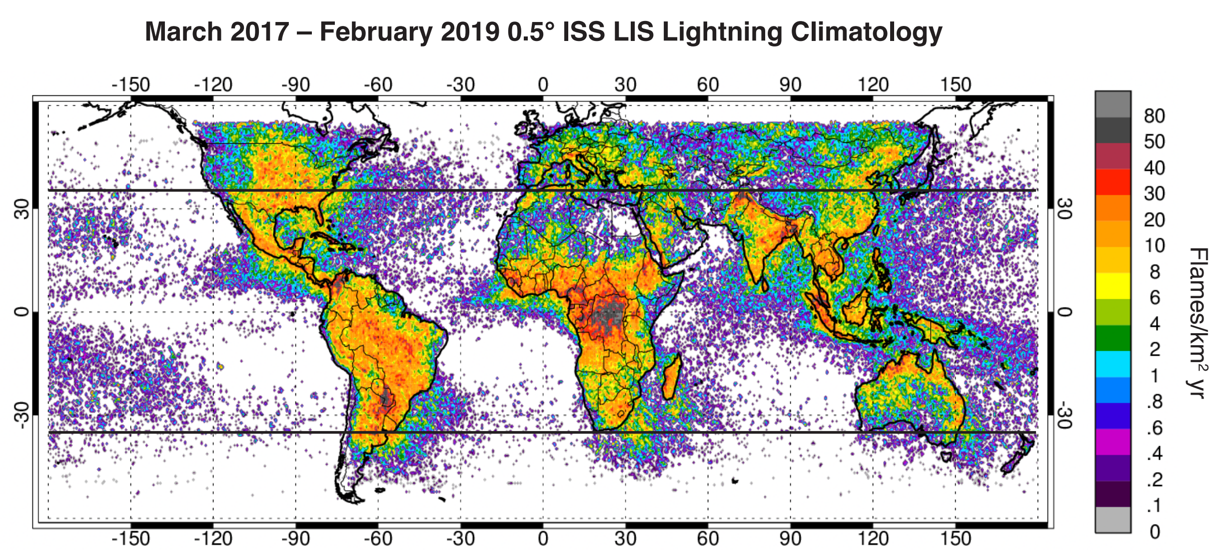
NASA's Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) measures Earth's surface temperature at different times of day from the International Space Station. Although its primary objective is to monitor the health of plants, ECOSTRESS can also detect heat events such as the one much of Europe just experienced.

ECOSTRESS mapped the surface, or ground temperature, of four European cities—Rome, Paris, Madrid and Milan—during the mornings of June 27 and June 28. In the images, hotter temperatures appear in darker shades and cooler temperatures appear in lighter shades. They show how the central core of each city is much hotter than the surrounding natural landscape due to the *urban heat island effect*—a result of urban surfaces storing and reradiating heat throughout the day.

The fact that surface temperatures were as high as 77–86 °F (25–30 °C) in the early morning indicates that much of the heat from previous days was stored by surfaces with high heat capacity (e.g., asphalt, concrete, and water bodies) and unable to dissipate it before the next day. The trapped heat resulted in even higher midday temperatures, in the high 40s (Celsius) in some places, as the heat wave continued. ■



Unique view of the SAGE III on ISS instrument. (*This photograph is referenced on page 3 of the Editorial.*) NASA's Orbiting Carbon Observatory–3 (OCO–3) was recently installed on the International Space Station's Japanese Experiment Module–Exposed Facility (JEM-EF). Before researchers could begin making measurements with OCO-3, they had to use a camera co-aligned with the instrument to double-check that the obstructions they expected to see on Station were exactly where they predicted they would be. As the camera scanned its surroundings, it caught this glimpse of SAGE III, which is installed on ExPRESS Logistics Carrier–4. **Photo credit:** NASA



Climatology of Lightning from the First Two Years of LIS Observations. (*This figure is referenced on page 2 of the Editorial.*) For the first time since the end of the Optical Transient Detector (OTD) mission in 2000, lightning can be observed over the entire continental U.S. and middle and southern Europe using LIS on ISS. The map shows annual global lightning flash rate density (Flashes/km^2 yr) from LIS on ISS during two years on orbit with view time and efficiency corrections applied. This climatology agrees with results obtained from OTD and LIS on TRMM. To emphasize the expanded mid-latitude coverage offered by LIS on ISS, the northern and southern limits of LIS on TRMM are shown as solid black lines for comparison. **Image credit:** NASA's Marshall Space Flight Center

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 a sampling of NASA Earth Science topics reported 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 Scientists Map Ground Damage Caused by California Earthquakes, July 9, *space.com*. Two recent Southern California earthquakes warped the ground across dozens of square miles—and the changes are visible even from space. A Japanese satellite picked up damage from the July 4 and 5 earthquakes that had magnitudes of 6.4 and 7.1, respectively. Earthquakes of these magnitudes are strong enough to cause moderate-to-severe damage to buildings. The July 5 earthquake was the strongest to hit the Ridgecrest region [150 mi (241 km), northeast of Los Angeles] in 40 years, according to the U.S. Geological Survey. The surface displacement caused by this temblor and its predecessor is clear in new images from Japan's Advanced Land Observing Satellite (ALOS-2) satellite, which gathers data using synthetic aperture radar to produce detailed measurements of the height of Earth's surface. Scientists at NASA/Jet Propulsion Laboratory (JPL) created a map based on the SAR data. Each color band represents 4.8 in (~12 cm) of ground displacement within the radar instrument's line of sight, JPL said in a statement. The USGS and the California Geological Survey, as well as other scientists, will use the map to assess damage and map the new faults. The region has also experienced 1000 aftershocks that opened up a few cracks.

Scientists Discover the World's Biggest Seaweed Patch. They Say It Could Be 'The New Normal.' July 9, *nbcnews.com*. With help from a pair of NASA satellites, scientists have identified what's being called the biggest patch of seaweed ever seen (more formally designated as the Great Atlantic Sargassum Belt, or GASB)—see **Figure**. The vast mat of brown *Sargassum* algae extends all the way across the Atlantic Ocean—a distance of about 5500 mi (~8851 km)—and the researchers say the so-called bloom may represent the "new normal" for parts of the Atlantic. "It goes all the way from West Africa, through the central Atlantic, towards the Caribbean Sea and reaching the Gulf of Mexico," said **Mengqiu Wang** [University of South Florida in Tampa], co-author of a paper describing the seaweed patch, published July 5, 2019, in the journal

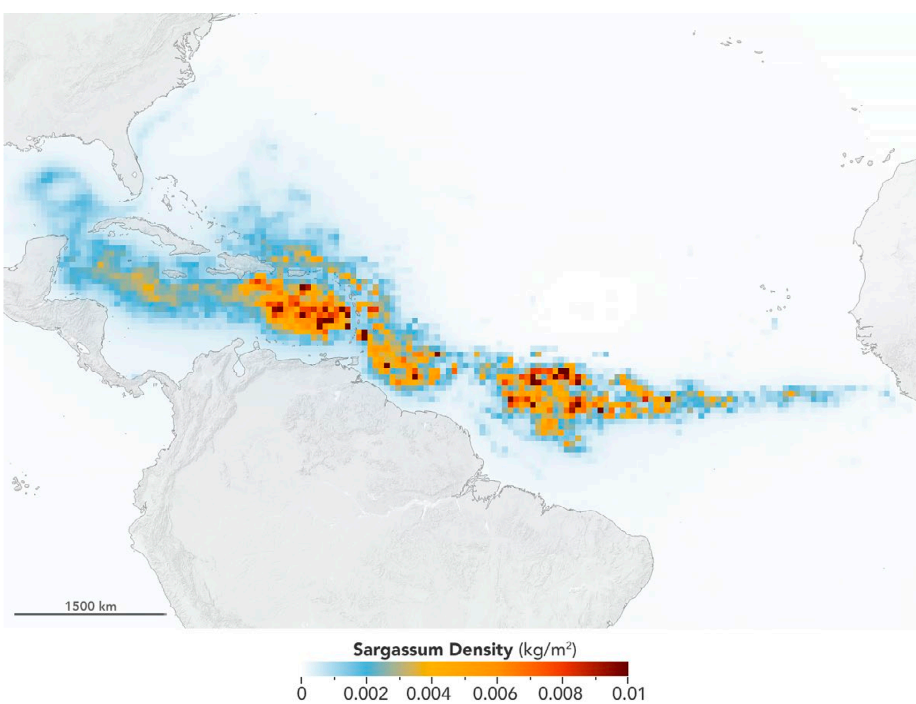


Figure. ***The Great Atlantic Sargassum Belt in July 2018***. Scientists analyzed data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra and Aqua satellites to discover the Great Atlantic Sargassum Belt (GASB). This feature was first observed in 2011, and has occurred every year since—except 2013. The GASB often stretches from the west coast of Africa to the Gulf of Mexico. **Image credit**: NASA/Earth Observatory produced the image; data provided by Mengqiu Wang and Chuanmin Hu [both at the University of South Florida]

Science. While such patches of Sargassum are nothing new (the researchers point out that Christopher Columbus and his crew reported seeing them as far back as the fifteenth century), the magnitude of the current bloom is unprecedented. Wang and her collaborators at the University of South Florida, the Florida Atlantic University, and the Georgia Institute of Technology identified the mat using 19 years of data from NASA's Terra and Aqua satellites. Prior to 2011 the seaweed was mostly limited to the Gulf of Mexico and the Sargasso Sea, an aptly named section of the Atlantic separated by ocean currents. But by 2011 the bloom extended into the central Atlantic, and by 2015 it stretched all the way across the Atlantic. Using data on ocean conditions from the same time period, the scientists tentatively linked the growth of the patch to rising levels of nutrients in seawater—including lots of nitrogen and phosphorous associated with deforestation and the rising use of fertilizers in Brazil. The chemicals have been seeping into the Amazon River, which then dumps them into the Atlantic. "Earth's ocean biogeochemistry is changing in response to natural and human forcings. The GASB suggests that we may be witnessing ecosystem shifts in our ocean that could have important implications for marine organisms and ecosystem services, which humans depend on," said **Paula Bontempi** [NASA Headquarters—*Acting Deputy Director of NASA's Earth Science Division* and *Program Manager for Ocean Biology and Biogeochemistry*].

NASA Is Tracking One of Earth's Most Valuable Resources – Water, June 18, *space.com*. Water can cause complex problems on Earth: For example, some places get far too little of it and some get far too much. That's why NASA and its international partners are tracking the flow of freshwater across the world in hopes of improving access to it for the billions who depend on it. Satellites provide data that scientists analyze to study how water moves through its cycle. Sometimes it evaporates from warm oceans in the tropics, condenses into clouds, and then falls back into the ground as snow or rain. The water might stay in a river or lake—or freeze, locked within ice or snow. It can either evaporate into the atmosphere or soak into the ground, moistening the soil or filling an aquifer. "Fresh water is critically important to humans, both in obvious ways and in unseen ways, such as moving heat around Earth's entire climate system," **Jared Entin** [NASA Headquarters—*Program Manager for Terrestrial Hydrology*]. "With our current satellites, we are now making great progress in pinning down both the detail needed for local water decisions and the global view essential to better understanding our changing climate."

* **Heatwave: Europe Is Burning at 114 Degrees in These Terrifying NASA Satellite Scans,** July 5, *express.co.uk*. Between June 26 and June 30, Europe was in the grips of one of the worst heatwaves on record. NASA's Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) collected data over Europe during the heatwave that have been analyzed to reveal the true scale of the scorching weather—see page 28 of this issue. During this period, temperatures across Europe peaked above 104 °F (40 °C), prompting widespread safety concerns. In France, for example, temperatures hit a new high on June 28, peaking at a sweltering 114.6 °F (45.9 °C) in the village of Gallargues-le-Montueux. That temperature broke the previous record of 111 °F (44.1 °C), which was set during a 2003 heatwave that killed thousands. In the aftermath of the heatwave, NASA announced that June 2019 has officially become the hottest month on record in Europe.

* See News Story in this issue for more details.

Interested in getting your research out to the general public, educators, and the scientific community? Please contact ***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

September 25–27, 2019
Sounder Science Team Meeting
College Park, MD
https://airs.jpl.nasa.gov/events/45

October 8–10, 2019
GRACE–FO Science Team Meeting, Pasadena, CA
https://grace.jpl.nasa.gov/events/15/grace-follow-on-science-team-meeting-pasadena-ca-usa

October 21–25, 2019
OST Science Team Meeting, Chicago, IL
https://sealevel.jpl.nasa.gov/science/ostscienceteam/scienceteammeetings

October 29–31, 2019
CERES Science Team Meeting, Berkeley, CA
https://ceres.larc.nasa.gov/science-team-meetings2.php

November 18–22, 2019
MODIS–VIIIRS Science Team Meeting College Park, MD
https://modis.gsfc.nasa.gov/sci_team/meetings

May 11–14, 2020
ABoVE Science Team Meeting, Fairbanks, AK
https://above.nasa.gov/index.html

Global Science Community

September 22–25, 2019
Geological Society of America (GSA), Phoenix, AZ
https://community.geosociety.org/gsa2019/connect/events

December 9–13, 2019
AGU Fall Meeting, San Francisco, CA
https://events.jspargo.com/AGU19/Public/enter.aspx

January 12–16, 2020
American Meteorological Society 100th Annual Meeting, Boston, MA
https://annual.ametsoc.org/2020

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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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