Over Thirty Years Reporting on NASA's Earth Science Program

The Earth Observer

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The Editor's Corner

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This Editorial reports on one successful launch, another scheduled for September, and new results from two existing missions–yet more evidence of continuing progress despite ongoing challenges imposed by the pandemic.

NASA's Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) Pathfinder mission successfully launched on June 30, 2021, onboard a SpaceX Falcon 9 as part of the SpaceX Transporter-2 mission that deployed 88 small satellites into Sun-synchronous orbits. A major initial challenge was locating and identifying the TROPICS Pathfinder satellite among 87 others. The MIT Lincoln Laboratory team worked with a number of satellite operators to execute a coordinated and systematic search. Contact was established on July 1, 2021, indicating that the satellite was alive and had properly initialized. Subsequent communication with the satellite confirmed that all satellite functionality is nominal, including attitude determination and control, GPS position and velocity, power generation and storage, avionics and data storage, and communications systems. The bus commissioning will proceed over the next two weeks or so, followed by payload commissioning for another two weeks and then checkout of the ground processing system. Global radiometric first light images are expected by October and dissemination of the TROPICS core data products (atmospheric vertical temperature and moisture profiles) are expected shortly thereafter.

continued on page 2

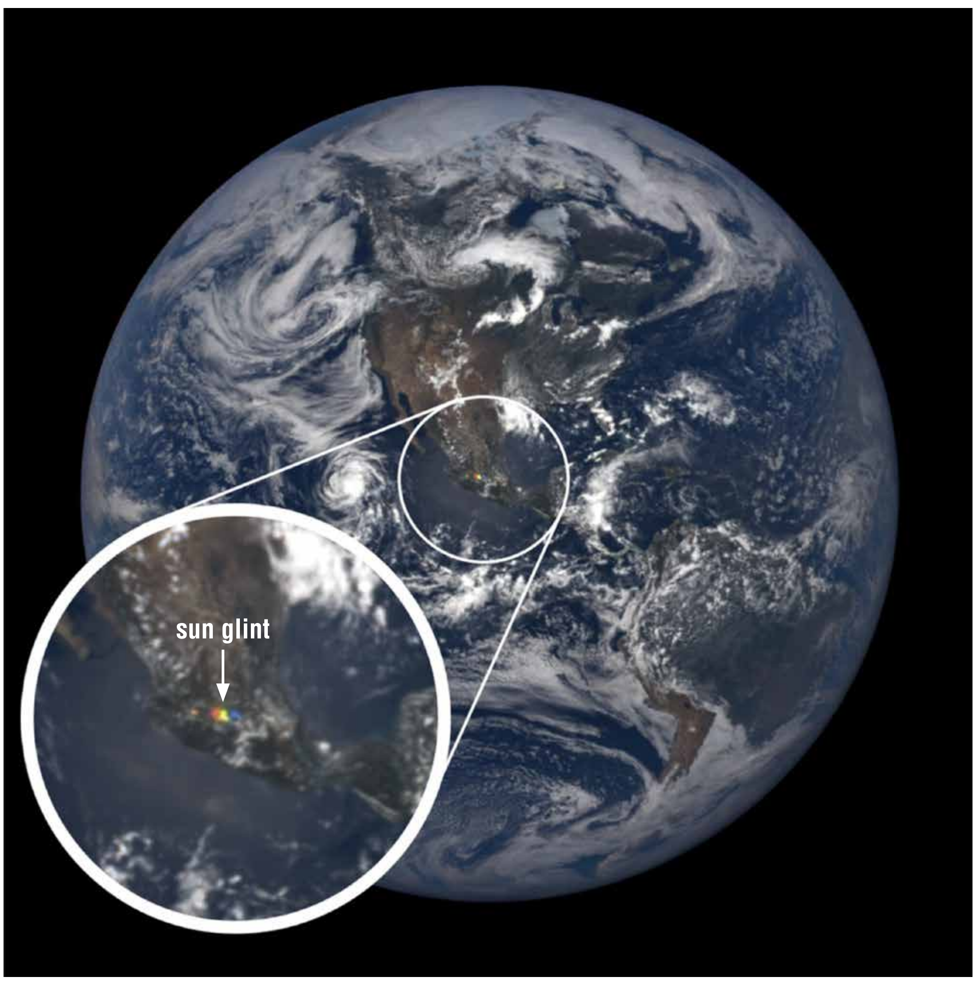

Figure. On July 4, 2018, at 16:39 Coordinated Universal Time (UTC), the EPIC instrument on DSCOVR captured this image that shows sunglint (caused by specular reflection ice crystals in high clouds) over Mexico. The inset image focuses on the glint region, which is centered about 200 km northwest of Mexico City. The original image can be viewed at *go.nasa.gov/3AdC9Cj*. **Image credit:** NASA/DSCOVR

In This Issue

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

As a *pathfinder*, the mission is intended to test the technology, communications systems, data processing, and data flow that will be used in the full TROPICS mission, which is scheduled for launch in 2022. TROPICS will employ a constellation of six Smallsats, each carrying a miniaturized microwave radiometer about the size of a coffee cup, to collect high-frequency temperature and humidity soundings that will help scientists better understand the physical phenomena that govern the development and intensity of tropical cyclones. Under certain conditions, tropical cyclones undergo *rapid intensification*—sometimes increasing wind speeds by as much as 100 mph (160 kph) in under two days. Current models struggle to accurately predict such rapid development. Frequent revisit views from the TROPICS constellation will be ingested by models and can lead to improvements in hurricane intensity forecasts. To learn more about TROPICS Pathfinder and plans for the full TROPICS mission, see the News story on page 21 of this issue.

Meanwhile, this issue's feature article is on Landsat 9, which is scheduled to launch on September 16, 2021, from Vandenberg Space Force Base in California onboard a United Launch Alliance Atlas V 401 rocket. The spacecraft will be inserted into a 705 km near-polar orbit where it will join the Landsat 8 satellite, essentially taking over the position Landsat 7 now occupies in the Morning Constellation. The launch of Landsat 9 will add a new and exciting chapter to the nearly 50-year story of Landsat observations. Turn to page 4 to learn more about Landsat 9. The article includes links to two previous articles in *The Earth Observer* that discuss Landsat.

Landsat has provided the longest continuous record of Earth's land surfaces from space. The consistency of Landsat's land-cover data from sensor to sensor and year to year makes it possible to trace land-cover changes from 1972 to the present. And now, the stage is being set to continue the seamless land imaging data record far into the future. Initial planning for a Landsat 9 follow-on mission—dubbed "Landsat Next"—is underway between NASA and the USGS. Draft requirements for Landsat Next have been published, which include up to 25 spectral bands, higher spatial resolution (up to 10 m), and improved revisit times. The Mission Concept Review (MCR), which will solidify the mission architecture and requirements, is anticipated for early 2022.

The Sentinel-6 Michael Freilich satellite, launched in November 2020, is now well on its way to replacing Jason-3 as the reference mission for measuring sea level across the globe. After a thorough assessment of the data quality by the mission team and a small community of experts, the first data from the satellite were publicly released on June 22, 2021. Initial assessments of the data show it to be of excellent quality. The data released include the *Near Real Time* data, which are available within three hours of collection, and the *Short Time Critical* data, which are released within 36 hours. While the near real time data are quite accurate (about 6 cm accuracy), the longer latency allows more and more accurate measurements of sea level to be made. The most accurate data product—the *Non-Time Critical* data—will have an accuracy of about 3 cm for a single measurement and be able to measure globally averaged sea level with an accuracy of a few millimeters.

The Non-Time Critical data quality is still being assessed and will begin to be released several months from now. It will typically have a 60-day latency. To learn more about Sentinel-6 Michael Freilich's current status, see the News story on page 20 of this issue.

Meanwhile much further out in space at the First Lagrange (L1) point of gravitational balance between Earth and the Sun, the Deep Space Climate Observatory (DSCOVR) is performing well after more than six years of operation. On May 27, 2021, DSCOVR executed a successful lunar calibration maneuver—where the spacecraft turns to look at the Moon—to allow for calibration of its two NASA Earth-observing instruments: EPIC and NISTAR.

The EPIC instrument continues to capture stunning images of Earth each day—from a distance of nearly 1.6 million km. EPIC multispectral imagery is also used to obtain global observations of a wide variety of environmental phenomena. Recently, the EPIC team released a new data product on sunglint (caused by the specular reflection of sunlight) that often appears in EPIC images—see **Figure** on the front cover. The product identifies glint from horizontally oriented ice crystals, as well as from smooth water surfaces such as calm ocean and lakes. More information about the glint product is available at *go.nasa.gov/3ioJjOd*.

An EPIC Ocean Surface Photosynthetically Available Radiation (PAR) product has also been released. EPIC observations in the 443, 551, and 680 nm bands are used to estimate daily mean PAR at the ice-free ocean surface. Information about the product and data access can be found at *go.nasa.gov/37jfR5R*.

Last but certainly not least, **Nickolay Krotkov** [GSFC] was selected as the next Aura Deputy Project Scientist, replacing **Joanna Joiner** [GSFC], who held the position since 2005. Krotkov's 30 years of experience, which includes Aura/OMI instrument evaluation and product development (sulfur dioxide, nitrogen dioxide), radiative transfer modeling, and related domestic and international satellite mission efforts, make him an excellent complement to **Bryan Duncan** [GSFC—*Aura Project Scientist*]. I extend my congratulations to Krotkov along with my many thanks to Joiner for her years of service to Aura. ■

List of Undefined Acronyms Used in Editorial and/or Table of Contents

CERES	Clouds and the Earth's Radiant Energy System
GPS	Global Positioning System
GSFC	NASA's Goddard Space Flight Center
EPIC	Earth Polychromatic Imaging Camera
MIT	Massachusetts Institute of Technology
NIST	National Institutes of Standards and Technology
NISTAR	NIST Advanced Radiometer
OMI	Ozone Monitoring Instrument
USGS	U.S. Geological Survey

The Legacy Continues: Landsat 9 Moves Landsat Toward a Golden Milestone

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The Landsat 9 mission is scheduled for a September 2021 launch from Vandenberg Space Force Base in California, aboard a United Launch Alliance Atlas V 401 rocket.

Introduction

The Landsat 9 mission is scheduled for a September 2021 launch from Vandenberg Space Force Base in California, aboard a United Launch Alliance Atlas V 401 rocket. The spacecraft will be inserted into near-polar orbit 705 km (438 mi) above Earth, where it will join the Landsat 8 satellite. The mission payload consists of two Earth-observing sensors: the Operational Land Imager 2 (OLI-2) and the Thermal Infrared Sensor 2 (TIRS-2). As is explained in this article, both of these sensors have slightly improved capabilities over identical (OLI-2) or very similar (TIRS-2) predecessor instruments on Landsat 8. The payload is integrated onto a spacecraft bus built by Northrop Grumman Space Systems.

Landsat 9 is a near copy of Landsat 8, and many of the details about the observatory, ground system, and instruments were explained in a 2013 article in *The Earth Observer* and so will not be repeated here.[1] Several footnotes in this article point the reader to where more information on specific topics can be found in that article.

The Earth Observer has reported extensively on the Landsat Program (hereinafter Landsat)—a series of Earth-observing satellite missions jointly managed by NASA and the U.S. Geological Survey (USGS). The two feature articles listed below contain historical information on Landsat as well as details on previous Landsat missions—see *Archived Landsat Articles from The Earth Observer*, below. **Figure 1** on page 5 shows a timeline of the Landsat missions.

In addition to the features, a search through *The Earth Observer* archives (*go.nasa.gov/3jSAvkR*) will reveal numerous Landsat Science Team (LST) Meeting summaries (typically two per year, held in summer and winter). These reports provide detailed accounts of the deliberations of the various incarnations of the LST and/or the technical development and scientific achievements of the individual missions.

While this article briefly summarizes Landsat history and repeats some details that have been presented before for storytelling purposes, its primary focus is on Landsat 9—and especially how it differs from Landsat 8. The majority of the text of this article was originally printed as a prelaunch brochure for Landsat 9.[2] The text has been modified in places to make it more suitable for publication in *The Earth Observer*.

[1] See "LDCM: Continuing the Landsat Legacy" in the March–April 2013 issue of *The Earth Observer* [**Volume 25, Issue 2**, pp. 4–9—*go.nasa.gov/2UvV6kq*]. Note that Landsat 8 was known as the Landsat Data Continuity Mission (LDCM) until 90 days after launch.
[2] See *Landsat 9: Earth from Space*, which can be viewed and downloaded from *go.nasa.gov/3xtvXVU*.

Archived Landsat Articles from *The Earth Observer*

Rocchio, Laura: "Chronicling the Landsat Legacy." November–December 2011 issue of *The Earth Observer* [**Volume 23**, **Issue 6**, pp. 4–10—*go.nasa.gov/2VgqYtr*]. This article reports Landsat history and includes anecdotes from some who were involved in the early years of Landsat. It discusses the program's evolution—up to and including Landsat 7.

Hobish, Mitchell K., Laura Rocchio, Darrel Williams, and Samuel Goward: "The Living Legacy of Landsat 7: Still Going Strong after 20 Years in Orbit." July–August 2019 issue of *The Earth Observer* [**Volume 31**, **Issue 4**, pp. 4–14—*go.nasa.gov/390VE6w*]. This article was written to mark the twentieth anniversary of the launch of Landsat 7 and as such focused on that mission. It is a retrospective as well as a look at the contributions Landsat 7 made to Earth science and related technical achievements of the mission.

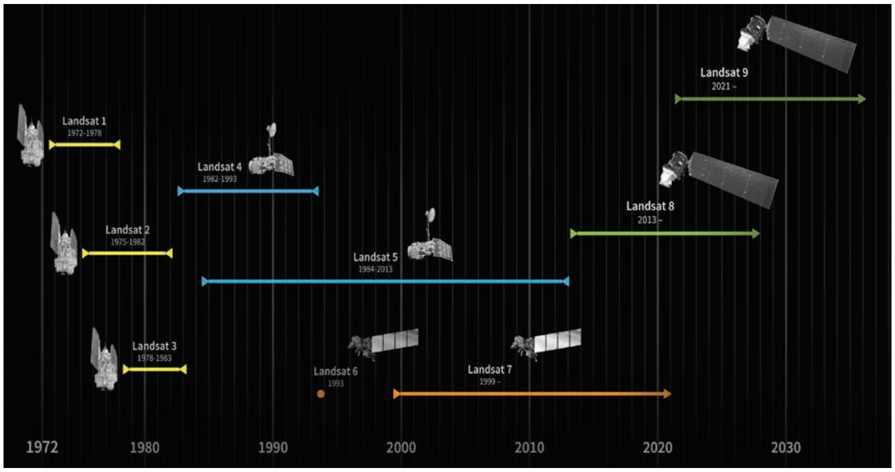

Figure 1. This graphic depicts the nine satellites that make up the Landsat series. Landsat 6 was lost in a launch failure in 1993. Landsats 7 and 8 are still operational, and Landsat 9 will continue the legacy of the Landsat missions' rich, global archive. **Image credit:** NASA

Landsat: Tracking Decades of Change

For nearly half a century, Landsat data have shaped our understanding of Earth. Since the launch of the first Landsat satellite (originally known as the Earth Resources Technology Satellite) in 1972, the mission has gathered and archived more than nine million images of our home planet's terrain, including crop fields and sprawling cities, forests, and shrinking glaciers. These data-rich images are free and publicly available, a circumstance that has led to scientific discoveries and applications through informed resource management.

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The continuous flow of Landsat data has enabled researchers to monitor global land cover for more than 49 years. With each pixel recording 30 m (98 ft) across—which is about the size of a baseball infield—Landsat images are detailed enough to detect both natural and human-caused changes to the landscape.

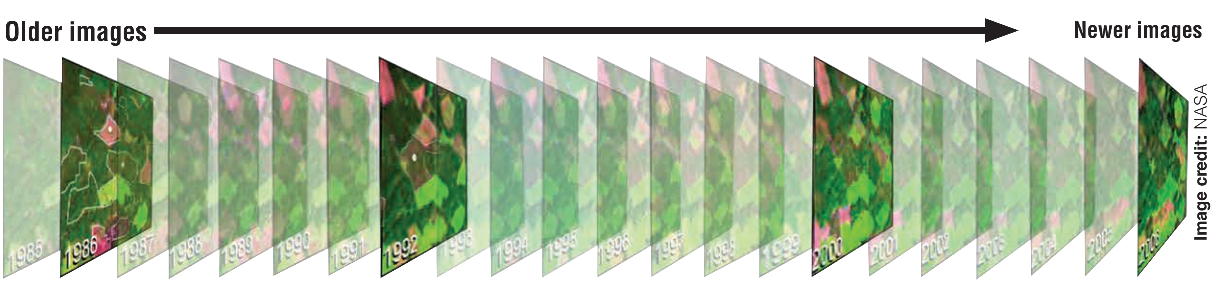
Indeed, more than 18,000 peer-reviewed research papers have used Landsat data. The mission helps determine the health of global crops and the extent of agricultural irrigation. It allows organizations to detect deforestation in remote areas of the globe and quantify the impact of wildfires. It also feeds efforts to improve wildlife habitat and prepare for natural disasters.

Landsat has provided the longest continuous record of Earth's land surfaces from space. The consistency of Landsat's land-cover data from sensor to sensor and year to year makes it possible to trace land-cover changes from 1972 to the present, and it will continue into the future with Landsat 9. With better technology than ever before, Landsat 9 will enhance and extend the data record to the 50-year mark and beyond.

Landsat 9: The Latest Chapter in the Landsat Story

The newest Landsat satellite strikes a balance between continuing the historical record and moving that record into the future. Using state-of-the-art technology, Landsat 9 will collect the highest-quality data ever recorded by a Landsat satellite, while still ensuring that these new measurements can be compared to those taken by previous generations of the Earth-observing satellite—see **Figure 2**.

Figure 2. Landsat 9 will have the same resolution as its predecessors, and the data will be precisely mapped to the globe so that researchers can study how each individual pixel changes over time. **Image credit:** NASA



Each day, Landsat 9 will add more than 700 scenes of Earth to the mission's archive. The near-polar orbit will allow the satellite's sensors to image almost the entire planet every 16 days. When Landsat 9 joins Landsat 8 in orbit, the two satellites together will be able to image each swath of the globe every eight days—see *Landsat 9 Quick Facts,* below. As Earth's population approaches eight billion people, Landsat 9 will continue to provide consistent and impartial data about the changing land cover and land use of our planet and enable enhanced studies of the footprint of the growing human population.

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Landsat 9 Instruments

The OLI-2 and TIRS-2 instruments on Landsat 9 largely replicate the instruments on Landsat 8.[3] Both are optical sensors that—between them—detect 11 wavelengths of visible, near-infrared, shortwave-infrared, and thermal-infrared light as they are reflected or emitted from the planet's surface. Data from the two instruments are processed and stored at the USGS Earth Resources Observation and Science (EROS) Center in Sioux Falls, SD, where decades' worth of data from all of the Landsat satellites are stored and made available—for free—to the public.

OLI-2

The OLI-2 instrument will produce stunning images of our home planet—e.g., algae swirling in the North Sea, teal-colored melt ponds on a bright white glacier, checkerboards of crop fields stretching for miles—but the purpose is far more than to take "pretty pictures" of Earth. The data behind these images will tell scientists and land managers much about the status of Earth's land surface—and when compared to previous Landsat images of the same location, how it is changing over time.

Within the OLI-2 instrument are thousands of detectors, aligned in rows. These detectors are sensitive to light reflecting off Earth's surface in nine different wavelengths. Using data from these bands, either individually or in various combinations, scientists can learn much about the condition of Earth's surface.

[3] Other than what is specified here, the two instruments are copies of their predecessors on Landsat 8. To learn more about OLI and TIRS, see pages 5–7 of "LDCM: Continuing the Landsat Legacy," as pointed to earlier.

Landsat 9 Quick Facts

Mission Management and Operations: NASA's Goddard Space Flight Center (GSFC) manages the development of Landsat 9 through its launch and post-launch checkout. The USGS Earth Resources Observation and Science Center operates the satellite and manages the data archive.

Spacecraft Provider and Observatory Integrator: Northrop Grumman Space Systems

OLI-2 Provider: Ball Aerospace & Technologies Corporation

TIRS-2 Provider: GSFC

Altitude: 705 km (438 mi)

Orbit Duration: 99 min

Orbits per Day: 14

Images per Day: 700+

Coverage of Earth: Every 16 days

Launch Vehicle: United Launch Alliance Atlas V 401 rocket

Launch Site: Vandenberg Space Force Base, CA

To access Landsat data, visit *www.usgs.gov/landsat*

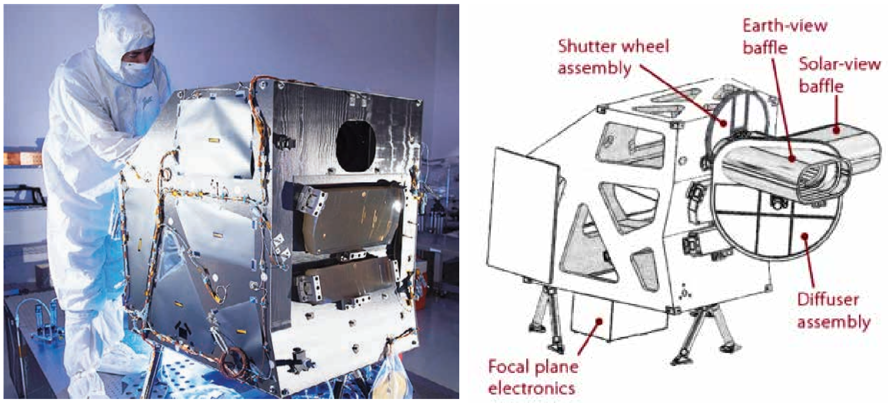

Figure 3. [*Left*] A technician at Ball Aerospace & Technologies Corporation works on OLI-2. [*Right*] Diagram of OLI-2 showing main components. Description available at *go.nasa.gov/3qXAf5K*. **Photo credit:** Ball Aerospace & Technologies Corporation

For example, healthy plants reflect near-infrared light, so strong signals in that band, relative to others, provide scientists with information about growing vegetation. Information from the shortwave infrared bands can help ecosystem managers identify regions that have been scarred by wildfires. Visible light bands revealing subtle color variations in lakes can help water managers identify potentially harmful algae blooms.

Several of these bands replicate the wavelengths detected by previous Landsat instruments—allowing Landsat 9 to maintain continuity with decades of previous observations. The Landsat 8 OLI instrument introduced two new bands: one that detects cirrus clouds and one that has improved observations of coastal waters and aerosols.[4] OLI-2 is essentially identical to OLI on Landsat 8—see **Figure 3**. However, Landsat 9 will downlink 14-bit data from OLI-2, as compared with 12-bit data from Landsat 8 OLI, leading to improved observations of darker regions for OLI-2, such as over forests and coastal waters, as well as over brighter regions, such as ice sheets.

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OLI-2 will have 30-m spatial resolution across most of its spectral bands. Altogether, the sensors cover a swath 185-km (115-mi) wide. This combination of a wide swath and moderate resolution allows OLI-2 to cover large areas, while still providing fine enough resolution to distinguish individual agricultural fields, forest plots, or housing developments—important information for urban planners, land resource managers, and commodity analysts.

TIRS-2

Whether it's a cornfield, a parking lot, or an iceberg, a fundamental rule of physics dictates that any surface will emit thermal infrared radiation, or heat, according to its temperature.[5] By detecting radiation in two thermal wavelengths, Landsat 9's TIRS-2 instrument can measure the temperature of our planet's ground and water.

TIRS-2 uses thermal bands to detect subtle shifts in surface temperature—within 0.1 °C (~0.2 °F). Its detectors are called *quantum well infrared photodetectors* (QWIPs) and were developed at NASA's Goddard Space Flight Center (GSFC).[6] Thermal infrared radiation in a specific wavelength will excite electrons within the QWIPs, creating an electrical signal that is used to determine temperature. **Figure 4** (on page 8) shows a photograph and diagram of TIRS-2.

Measuring surface temperatures from space can be difficult, however, as atmospheric moisture and air temperature can skew the signals. The atmosphere affects each of the

[4] To learn more about the spectral coverage of OLI-2, see Figure 1 on page 6 of "LDCM: Continuing the Landsat Legacy," as pointed to earlier.

[5] The Stefan–Boltzmann law requires this, as it dictates that the power radiated from an idealized *black body* in terms of its radiant emittance is directly proportional to the fourth power of its temperature.

[6] To learn more about QWIPs, see page 7 of "LDCM: Continuing the Landsat Legacy," as pointed to earlier.

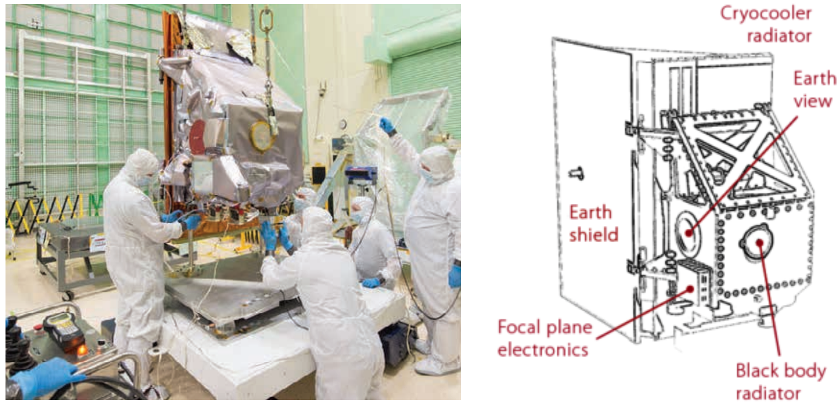

Figure 4. [*Left]* Engineers at GSFC work on TIRS-2, which will measure temperatures on Earth's surface from the Landsat 9 satellite. [*Right*] Diagram of TIRS-2 showing main components. Description available at *go.nasa.gov/3AInmk7*. **Photo credit:** NASA

TIRS-2 thermal bands slightly differently, resulting in a thermal image from one of the bands that is slightly darker than the other. Algorithms can analyze that difference to compensate for such atmospheric effects, creating a more accurate temperature record of Earth's surface.

Unlike OLI-2, TIRS-2 is slightly modified from its predecessor on Landsat 8. While it works on the same principles as the original TIRS, it corrects a problem the first instrument had with scattered light inside the telescope. In addition, the electronics were made redundant to bring the instrument to Class B, as defined by *NASA Procedural Requirements*.[7] In practical terms, this means that while TIRS has a three-year design life, TIRS-2 is built with increased robustness and redundancy to last at least five years.[8] TIRS-2, like OLI-2, is a "push-broom" sensor with arrays of detectors that line up to observe a field of view that is 185 km across, with a resolution of 100 m (328 ft)—see **Figure 5.**

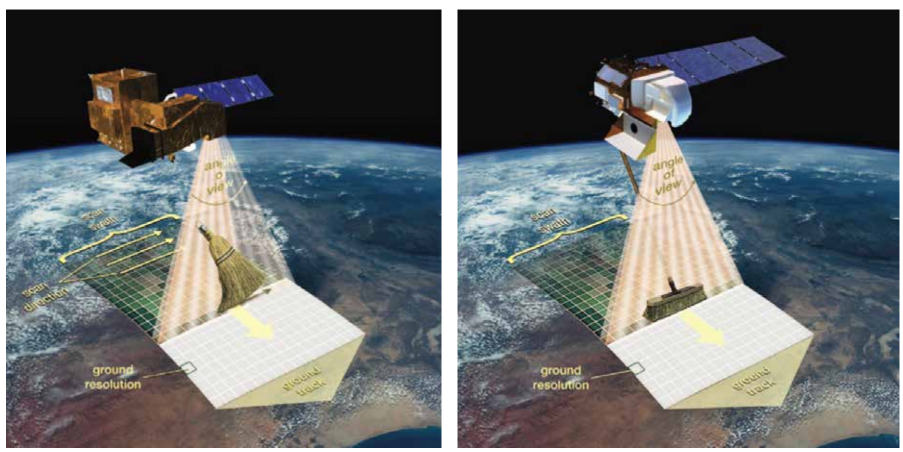

Figure 5. [*Left image*] Previous Landsat sensors (i.e., the Multispectral Scanner System, Thematic Mapper, and Enhanced Thematic Mapper Plus) used mirrors that swept back and forth, across the swath like a *whisk broom* to collect data. This sensor design requires fast-moving parts, which are subject to wear. [*Right image*] New technologies allow OLI to view across the entire swath at once, building strips of data like a *pushbroom*. The advantages are that pushbroom sensors require fewer moving parts and are more sensitive than whisk-broom sensors. **Image credit:** NASA

Water resource managers, who use temperature measurements from the Landsat satellites to help track agricultural water use, advocated for the inclusion of the original TIRS on Landsat 8. Water in the soil, as well as water released from a plant's leaves as it undergoes transpiration, results in cooler temperatures over irrigated, healthy crops—which can be detected in TIRS data.

Since the Landsat thermal bands can penetrate smoke that might otherwise obscure the view, scientists and resource managers can use TIRS observations to locate the perimeters of active fires. TIRS data can also be used to "see" in the polar night, tracking icebergs in winter when there is little visible light for other bands to detect.

[7] These requirements are downloadable from *nodis3.gsfc.nasa.gov/npg_img/N_PR_8705_0004_/N_PR_8705_0004__AppendixB.pdf.*
[8] The three-year design life was a concession to expedite development of TIRS.

Launch and Operations

The two instruments onboard Landsat 9 are integrated onto a spacecraft bus that has a design similar to the one used for Landsat 8. The bus is the satellite's power source and provides orbit control, propulsion, navigation, communications, and data storage.[9]

Four solar panels will deploy after launch to charge the spacecraft's battery. An onboard data recorder will store up to four terabits of data before the data are transmitted to one of three ground stations—at Gilmore Creek, AK; Sioux Falls, SD; or Svalbard, Norway.

The data are archived at the USGS EROS Center in Sioux Falls, which also generates the data products used by scientists, resource managers, and other users. The other element of the Landsat 9 ground system consists of the Mission Operations Center (MOC) at GSFC, which issues software commands to control the satellite observatory and direct science data collection.[10]

An Invaluable Data Archive

To investigate how Earth has changed in the last half-century, look to Landsat. The mission's archive is a continuous data record of natural and human-caused changes to land, ice, and water since 1972.

Containing more than nine million images, the Landsat data archive provides researchers and decision makers with an essential tool to understand and manage our planet's food, water, and forests. The archive contains raw, newly acquired data as well as refined products depicting burned areas, snow cover, surface reflectance, water, and temperature. While the data exist in formats ready for experienced analysts and researchers, tools such as the USGS Global Visualization Viewer (GloVis, *glovis.usgs.gov*) and EarthExplorer (*earthexplorer.usgs.gov*) also allow individuals to view and search images directly from their web browsers.

In 2008 USGS made the entire Landsat archive free and available to the public. The archive is open for interested parties to investigate vast geographic areas and temporal spans—studies that were often cost prohibitive before the archive opened. Since 2008 the number and complexity of studies using Landsat data have grown exponentially.

The advent of big-data analysis and cloud computing have further unlocked the archive's power. By using cloud-computing platforms and other powerful analysis tools, researchers can quickly and accurately look for patterns and changes across decades-long timeframes or large swaths of the globe. See *Continuing the Legacy* on pages 10 and 11 for several examples of the myriad ways Landsat data are being applied to address real-world concerns.

The Landsat archive gives researchers power to investigate questions about our changing world. With access to this one-of-a-kind archive of terrestrial imagery, we can monitor our natural resources at local and global scales and empower natural-resource managers to make informed decisions for the future.

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Conclusion

The NASA–USGS Landsat Program has achieved almost five decades of continuous operations. The launch of Landsat 9 will add a new and exciting chapter to this nearly 50-year story of Landsat observations. When it launches, Landsat 9 will join two family missions already in orbit: Landsat 7 and 8. As of this writing, both Landsat 7 and 8 are operating nominally—the long-standing scan-line corrector issue on

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[9] To learn more about the Landsat 9 spacecraft design, see page 7 of "LDCM: Continuing the Legacy," noted earlier.

[10] To learn more about the Landsat 9 ground system, see page 8 of "LDCM: Continuing the Legacy," as pointed to earlier.

Continuing the Legacy

When it launches, the NASA–USGS Landsat 9 mission will add a new chapter to a nearly 50-year legacy of high-resolution land observations made by previous Landsat missions. The new satellite is designed to allow for continuity with its predecessors (and for intercomparison with other international land imaging missions). The data collected are used for myriad applications that address real-world concerns, several of which are highlighted here. Several other examples are shown in the Landsat 9 brochure that was the basis for this article. Color versions of all the images shown here can be found in the brochure and also in the online version of *The Earth Observer*.

Tracking Water Quality

Image credit: NASA

Spotting Algal Blooms from Space. Harmful algal blooms 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 data from Landsat and other Earth-observing satellites to help. With its medium resolution, Landsat can gather data on smaller lakes than other satellites can, allowing scientists to track water quality information from more than 60% of the U.S. lakes and reservoirs, or more than 170,000 water bodies. The image here shows an algal bloom in western Lake Erie, taken by Landsat 8's OLI on September 26, 2017.

Disaster Response

Burned Area Emergency Response Maps. Before wildfires stop smoldering, forest restoration specialists are on the job. They analyze maps created using Landsat satellite data, called *Burned Area Emergency Response maps*, to determine where a burn destroyed vegetation and exposed soil—and to identify where to focus emergency restoration efforts. These maps can save federal agencies as much as $7.7 million annually in post-fire costs, according to a 2019 study. Fire managers analyze before-and-after images from the near-infrared band, which reflects strongly from healthy vegetation, and the shortwave-infrared band, which reflects strongly from exposed ground, to identify scorched areas. The images below show the location of the 2013 Silver Fire in New Mexico. The "before" image [*left*] is a false-color Landsat 8 image acquired May 28, 2013. The "during" image [*middle*] shows the location of the fire (hot spot) and burn scar on June 13, 2013, while the fire was still growing. The image on the right is an example of a Burned Area Emergency Response map created using Landsat data, showing areas with high, moderate, and low severity burns. Fire managers use maps like these to direct restoration resources.

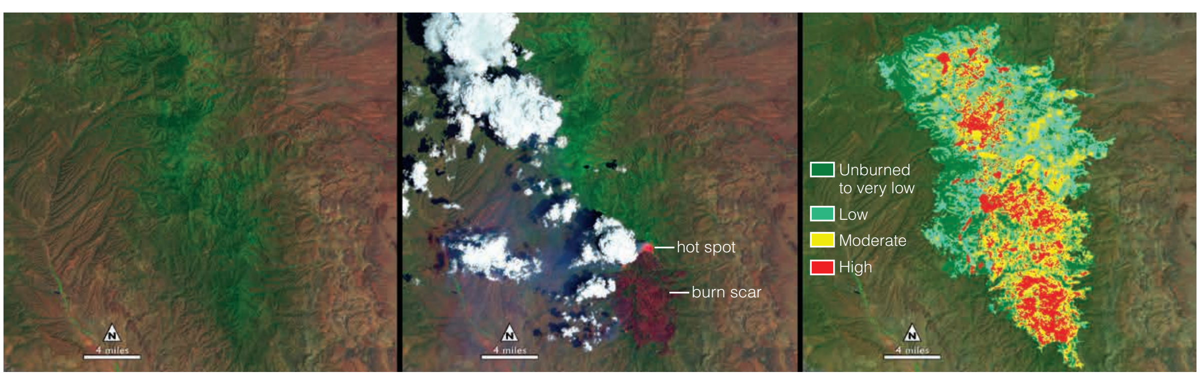


Image credit: USDA Forest Service, Burned Area Emergency Response Team

Ice Observations

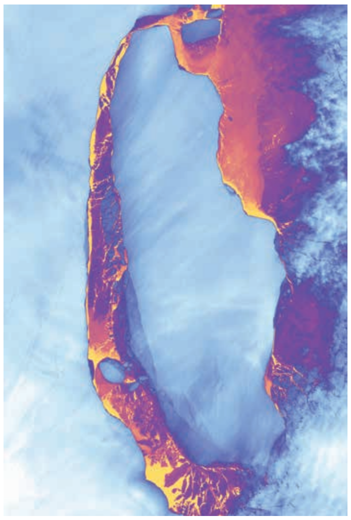


Image credit: NASA

Tracking Ice in Polar Darkness. Under the cloak of Antarctica's polar night, a massive iceberg calved from the Larsen C Ice Shelf in July 2017. Despite the lack of sunlight, thermal images from the TIRS instrument on Landsat 8 were able to tell the story of how a chunk of ice about the size of Delaware broke loose from the Antarctic Peninsula. On September 16, 2017, TIRS took this false-color image of the iceberg, showing the relative warmth or coolness of the surfaces, allowing scientists to track its split and movement. Lighter shades of blue indicate the coldest surfaces, including the ice shelf and thick iceberg. The purple and orange shades (around the edge of the iceberg) are regions of thin sea ice, and regions of mixed water, ice, and snow, called *mélange*. The lightest orange areas around the edges are where the warmest surfaces are found, e.g., the open water between the shelf and iceberg.

Tracking Climate Change Impacts

Image credit: NASA

Landsat Reveals Greening Across North America's Arctic. The northern reaches of North America are getting greener, according to a NASA study that examined plant life across Alaska and Canada. In a changing climate, almost one-third of the land cover—much of it Arctic tundra—is looking more like landscapes found in warmer ecosystems. With 87,000 images taken from Landsat satellites between 1984 and 2012 converted into data that reflect the amount of healthy vegetation on the ground, the researchers found that western Alaska, Quebec, and other regions became greener over three decades. Rapidly warming temperatures in the Arctic have led to longer growing seasons for plants and changes to the soils. Grassy tundra changes to shrubland, and shrubs grow bigger and denser—changes that could impact regional water, energy, and carbon cycles.

feature article

Between the impending launch of Landsat 9 and the ongoing planning for Landsat Next, the future of the Landsat data stream looks "bright."

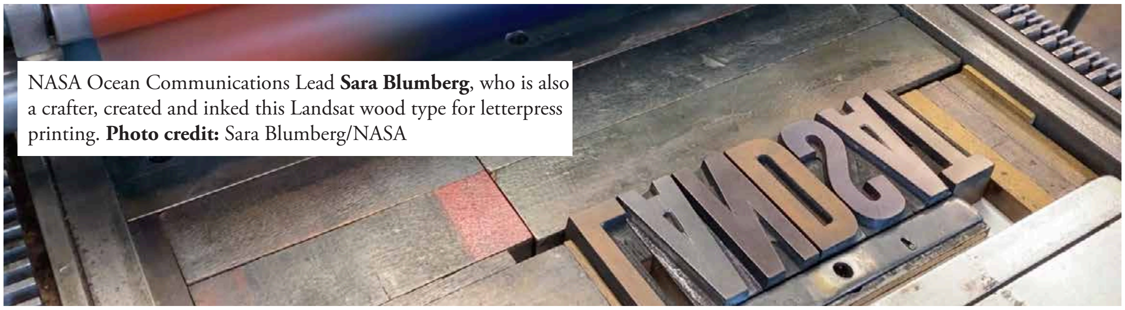
Landsat 7 notwithstanding.[11] However, Landsat 7 is nearing its end of life (based on maneuvering fuel availability) and will cease to provide scientifically usable data in late 2021. When Landsat 9 reaches orbit, Landsat 7 will almost immediately begin its exit from the "Morning Constellation"[12] and move toward a lower orbit.[13] Landsat 9 will effectively take over the position that Landsat 7 occupied in the constellation.

Similar to other Earth-observing missions, USGS has moved to a collection-based data-processing approach. New surface-reflectance and temperature standard products are now available via Collection 2. At the same time, the scientific community continues to find innovative uses for the archive beyond those mentioned in this article, including large-scale ice-velocity mapping for Antarctica, global deforestation products, and improved estimates of cropland water consumption via monitoring evapotranspiration.

As for the longer-term future of Landsat, initial planning for a Landsat 9 follow-on mission (dubbed "Landsat Next") is underway between NASA and USGS. Draft requirements for Landsat Next have been published, which include up to 25 spectral bands, higher spatial resolution (up to 10 m, or ~33 ft), and improved revisit times. The Mission Concept Review (MCR), which will solidify the mission architecture and requirements, is anticipated for early 2022. Between the pending launch of Landsat 9 and the ongoing planning for Landsat Next, the future of the Landsat data stream looks bright. ■

[11] To learn more about the SLC failure on Landsat 7, see page 7-8 of "The Living Legacy of Landsat 7: Still Going Strong after Twenty Years in Orbit," referenced in the Introduction.
[12] The current Morning Constellation consists of the Landsat 7 and 8 satellites and Terra.
[13] The current plan is for Landsat 7 to lower its orbit in early 2022, perform some coordinated science with Landsat 9, and then prepare for a servicing mission via the On-orbit Servicing and Manufacturing (OSAM-1) spacecraft, which is currently scheduled to launch in January 2025 (*go.nasa.gov/3jWeHVj*).

NASA Invites You to Create Landsat-Inspired Arts and Crafts



NASA Ocean Communications Lead **Sara Blumberg**, who is also a crafter, created and inked this Landsat wood type for letterpress printing. **Photo credit:** Sara Blumberg/NASA

For almost 50 years, Landsat satellites have collected images of Earth from space, representing the longest continuous space-based record of our planet's surface. It is a joint mission of NASA and the U.S. Geological Survey (USGS), and both scientists and the public have free access to the nine million scenes in this invaluable archive. Landsat images provide the ability to observe changes in Earth's landscapes and coastal regions over time.

The images can be strikingly beautiful—see the *Earth as Art* galleries from our partners at USGS (*eros.usgs.gov/image-gallery/earth-as-art*) and an eBook from NASA (see access details in Step 1, below)—but they're much more than that. Behind the images are highly calibrated data that land managers and policy makers use to make decisions about Earth's resources and our environment. Landsat has long provided often unique information about agricultural productivity, ice sheet dynamics, urban growth, forest monitoring, natural resource management, water quality, and the impacts of climate change on our planet. Landsat 9 is scheduled for launch in September and will continue this legacy.

In honor of the Landsat 9 launch, we invite you to get creative and show us what Landsat means to you! Create art or make a craft that's inspired by a favorite Landsat image or the satellite itself and share it on social media.

How To Create and Share Your Craft

1. Search the Landsat Image gallery (*landsat.visibleearth.nasa.gov*) and/or *Earth as Art* gallery (*www.nasa.gov/connect/ebooks/earth_art_detail.html*) for an image that inspires you.

2. Get crafting! This can be anything from watercolor paintings to knitted accessories to a tile mosaic—whatever sparks your creativity.

3. Share your creation on social media using the hashtag #LandsatCraft as detailed on the next page.

[*Above*] Scientists created the Landsat Image Mosaic of Antarctica by stitching together more than 1,000 Landsat 7 images [*left*]; science writer **Kate Ramsayer** [NASA's Goddard Space Flight Center (GSFC)] created her mosaic of Landsat 7 and Antarctica by arranging dozens of stained-glass pieces [*right*]. **Image credit**: Kate Ramsayer/NASA

continued on next page

More on Creating and Sharing Your #LandsatCraft (continued from page 13)

After you have finished creating your Landsat-inspired craft or piece of art, take a picture and upload it to Twitter, Instagram, or Facebook. Make sure you use the hashtag #LandsatCraft so we know that you are taking part in the event.

If a #LandsatCraft post catches our eye, we may share your work on our @NASAEarth social media accounts. We may also feature your art in a NASA Flickr gallery. You can follow @NASAEarth on Twitter, Instagram, and Facebook for submission updates and featured art throughout the summer.

Images of agriculture from space often combine bright colors and interesting shapes and lines. NASA Earth science social manager **Katy Mersmann** [GSFC] created embroidery based on an image of canola fields in Canada. **Image credit**: Katy Mersmann/NASA

#LandsatCraft Terms and Conditions

When submitting your image(s) to the #LandsatCraft campaign, you confirm to NASA that:

- The artwork was produced by you (i.e., it's your original work);
- the contents of the artwork do not infringe upon the copyright or any other right of any third party;
- the artwork contains no inappropriate content;
- you are either more than 18 years of age or an emancipated minor, or you possess legal parental or guardian consent. In any case, you affirm that you are over the age of 13; and
- in the event any individual is featured in the artwork, you represent and warrant that such individual agrees that NASA may use such individual's name and likeness in connection with NASA's use of the image hereunder.

Your artwork must also comply with the terms of service for social media sites such as the following:

Flickr: *https://www.flickr.com/help/terms*

Instagram: *http://instagram.com/legal/terms*

Twitter: *https://twitter.com/tos?lang=en*

Facebook: *https://www.facebook.com/terms.php*

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Be advised that social media posts and websites that specifically list prices or "click here to purchase" wording cannot be shared by government accounts.

Summary of the Thirty-Fourth and Thirty-Fifth CERES Science Team Meetings

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

Introduction

The thirty-fourth and thirty-fifth Clouds and the Earth's Radiant Energy System (CERES) Science Team Meetings (STMs) took place September 15–17, 2020, and May 13–15, 2021, respectively. Due to the ongoing COVID-19 pandemic, both meetings were held virtually with NASA's Langley Research Center (LaRC) in Hampton, VA, acting as the online host for the meetings. **Norman Loeb** [LaRC—*CERES Principal Investigator (PI)*] conducted both meetings.

The Spring 2021 meeting was the first official joint meeting with the Libera Project (*lasp.colorado.edu/home/libera*).[1] However, several presentations during the Fall 2020 meeting focused on Libera. The reader is referred to the section on "Libera Programmatic and Technical Presentations" on page 17 of this issue for more details on the current status of Libera and emerging plans for data products.

Selected highlights from both meetings are summarized in this article. More information on these and other topics is available on the CERES website at *ceres.larc.nasa.gov/science/presentations*.

CERES Programmatic and Technical Presentations

Each CERES meeting starts with the CERES PI giving a "State of CERES" report, which is an opportunity to highlight significant information about the project. A variety of programmatic reports from NASA and/or the CERES team leads typically follow the State of CERES report. Topics covered in these presentations include technical updates on the satellite platforms carrying CERES instruments[2] and updates on various mission components (e.g., instruments, ground systems, data products). This summary gives the highlights from the Fall 2020 and Spring 2021 State of CERES presentations and other programmatic presentations selected for their impact on future CERES activities.

State of CERES

At both meetings, **Norman Loeb** gave an update on the performance and calibration of all CERES instruments. He reported that there has been no change in their health and that their calibrations remain constant. Loeb also outlined the other major meeting objectives, which were to;

- highlight key changes for Edition 5 products including NASA's Goddard Space Flight Center (GSFC) Global Modeling and Assimilation Office's (GMAO's) atmospheric reanalysis, new MODIS[3] Collection 7, code improvements, and algorithm improvements, especially to enable seamless transition across satellite platforms;
- demonstrate the progress on Terra and Aqua Edition 5 development;
- highlight key scientific research resulting from the CERES data; and
- discuss data product validation.

During the Fall 2020 meeting, **Norman Loeb** explained how the NOAA-20 FM-6 instrument would be used to fill the afternoon data gaps that occurred when the Aqua Formatter Multiplexer Unit (FMU) experienced an anomaly that prevented reading science data from the solid-state recorder on August 16, 2020. The CERES FM-3 and FM-4 instruments were placed in safe mode pending resolution of the problem. A reset of the FMU software resolved the problem and the CERES instruments returned to normal operations on September 2, 2020.

A key topic of discussion during the Spring 2021 meeting was the pending drift of the Terra and Aqua satellites out of their mean local time (MLT) of Equatorial crossing. The last Terra and Aqua inclination adjustment maneuvers have already occurred. They are expected to exceed a 15-min change in MLT, limited to avoid discontinuity in the CERES record, in October 2022 for Terra and mid-2022 for Aqua.[4] This presents two challenges to the CERES team: adapting multisatellite products to not have information in the morning orbit and ensuring that bringing in a new afternoon satellite (NOAA-20) with a different imager, will not cause a spurious jump in the flux and cloud property time-series trends—see William Smith Jr.'s presentation on the next page for more details. The latest Terra and

[1] Libera was introduced on page 24 of the "Summary of the Thirty-Second and Thirty-Third CERES Science Team Meetings" in the July–August 2020 issue of *The Earth Observer* [**Volume 32**, **Issue 4**, pp. 21–26—*go.nasa.gov/3hpccJz*].

[2] There are currently six CERES instruments active on four satellites: two on Terra [Flight Model-1 (FM-1) and FM-2]; two on Aqua [FM-3 and -4]; one on the Suomi National Polar-orbiting Partnership (NPP) [FM-5]; and the National Oceanic and Atmospheric Administration's (NOAA)-20 satellite [FM-6].

[3] MODIS stands for Moderate Resolution Imaging Spectroradiometer, which flies on NASA's Terra and Aqua satellites.

[4] It seems counterintuitive that Aqua, which launched later, would exceed its 15-min change in MLT before Terra. However, because Aqua is part of the A-Train it is in a lower orbit than Terra, which causes it to drift more quickly—but with less certainty. Hence, the "mid-2022" designation as opposed to a specific month as with Terra.

Aqua Senior Review granted funding for both missions through September 2023, with an extension being considered after the March 2023 Senior Review.

David Considine [NASA Headquarters (HQ)] spoke during the Fall 2020 meeting about the contribution that Michael Freilich, the former Director of NASA's Earth Science Division (ESD), who passed away in August 2020, made to Earth Science during his career.[5] In his interactions with Freilich, Considine observed Freilich's commitment and caring about the ESD mission, his always being prepared when he walked into a meeting, and his willingness to make hard decisions and take responsibility for them. Considine announced that Frelich's successor is Karen St. Germain. She brings to NASA experience gained overseeing the Joint Polar Satellite System (JPSS) and Geostationary Operational Environmental Satellite (GOES)-R programs while she was Deputy Assistant Administrator, Systems, for the National Oceanic and Atmospheric Administration's (NOAA's) National Environmental Satellite, Data, and Information Service (NESDIS). Considine also discussed the Terra, Aqua, and Suomi NPP Science Team proposals, which were under review at the time of the meeting—with the expectation of 50 to 60 awards. He ended his presentation with an update on ESD satellite status.

William Smith, Jr. [LaRC] described various efforts being undertaken to improve consistency in cloud fraction and properties derived from the MODIS and Visible Infrared Imaging Radiometer Suite (VIIRS) imager radiances.[6] These efforts are necessary because VIIRS does not have the same channels as MODIS and the central wavelengths on some of the common channels differ. This effort also includes integrating input from 21 geostationary satellites, each with varying numbers of channels—and even variation in specific wavelength bands for those with the same number of channels. Five of the 21 satellites are used at any particular time to provide global coverage. The numbers of channels on a particular satellite have increased from 3 on the satellites used at the start of CERES (2000) to 16 on the satellites currently in use. This complicates developing the cloud properties and the narrowband to broadband radiance conversion that are incorporated into the CERES synoptic one-degree (SYN1deg) products. One of the approaches for NOAA-20 is to use the recently developed Cross-track Infrared Sounder (CrIS)[7] fusion radiance (FSNRAD) product that provides radiances for MODIS channels not included on VIIRS. Other efforts are applying machine learning to address challenging cloud retrieval problems.

Seiji Kato [LaRC] presented preliminary analysis of removing Terra data (both MODIS and CERES instruments) from the surface fluxes in SYN1deg and Energy Balanced and Filled (EBAF) products. Without Terra—but including geostationary imager information[8]—there is up to a 5 W/m^2 regional discontinuity in downward shortwave and longwave surface fluxes. Without including geostationary imagers, there is a global -0.35 W/m^2 difference in shortwave (SW) and longwave (LW) surface fluxes. This is related to having less cloud cover over marine stratocumulus regions and more afternoon convective clouds over land. Kato also highlighted the impact of artifacts caused by cloud properties received from geostationary imagers.

David Doelling [LaRC] outlined a study to quantify the impact of the drift in the Terra Equatorial crossing MLT from its current crossing time of 10:30 AM to either 10:15, 10:00, or 9:00 AM. Geostationary Earth Radiation Budget (GERB)[9] data, covering the Eastern Atlantic, Europe, and Africa, were sampled at the current 10:30 crossing time and then again by subtracting 15, 30, and 90 minutes from the Terra observation time. These synthetic datasets were then run through the Single Scanner Footprint one-degree (SSF1deg) process and compared. The top of the atmosphere (TOA) SW flux within the domain increased by 0.34, 0.80, and 2.73 W/m^2, respectively. This change is mostly caused by catching more morning Namibian stratus clouds at the earlier times. The impact on TOA LW flux is smaller, but very noisy. Based upon this analysis, an MLT change of up to 15 minutes from the current MLT on Terra, and also the current MLT on Aqua, will have minimal impact on the quality of the CERES Earth Radiation Budget (ERB) climate data record (CDR). Once the Terra and Aqua MLTs exceed 15 minutes from their current values, CERES Terra and Aqua data will be used to address new science questions related to ERB diurnal cycle variability and CERES FM-6 on NOAA-20 will be used to extend the existing CERES ERB CDR.

Ryan Scott [LaRC/Science Systems and Applications, Inc. (SSAI)] described results from running the Cloud Radiative Swath (CRS) code—something that had not been done for over a decade due to lack of computational resources. Other efforts to improve the parameterizations used to obtain surface fluxes have not been

[5] To learn more about Freilich's contribution to Earth science, see "Symposium on Earth Science and Applications from Space with Special Guest Michael Freilich," in the January–February 2020 issue of *The Earth Observer* [**Volume 33, Issue 1**, pp. 4-18—*go.nasa.gov/3lsbsDG*].

[6] Like CERES, MODIS instruments fly on NASA's Terra and Aqua platforms. VIIRS instruments fly on the Suomi National Polar-orbiting Partnership (NPP) satellite and on NOAA-20.

[7] CrIS instruments fly on the Suomi NPP and on NOAA-20.

[8] To provide information on the diurnal cycle of fluxes and clouds, several CERES products incorporate radiances and cloud properties from five geostationary imagers spaced around the globe (see *go.nasa.gov/2TKKmi9*).

[9] GERB flies on the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT's) Meteosat Second Generation (MSG) geostationary satellites.

successful, so with computer efficiency improving this technique is being given a new look. The CRS provides top of atmosphere, atmosphere, and surface flux by using the Fu–Liou radiative transfer model and cloud information for each CERES footprint. The observed-vs.-modeled TOA LW and SW flux had a global bias of 7 and 30 W/m^2, respectively, for 2019. The modeled-vs.-parameterized surface LW and SW fluxes had a reduction of 17 and 34%, respectively. Scott also presented preliminary results on applying supervised machine learning algorithms to obtain surface fluxes.

Libera Programmatic and Technical Presentations

Libera was selected in February 2020 as the winning Earth Venture Continuity–1 mission, as defined by the 2017 Earth Science Decadal Survey,[10] which called for missions that continue the Program of Record for key observations—but to do so more efficiently. Libera is a low-cost, cost-capped mission that will extend current NASA Earth Radiation Budget climate data records. In essence, this makes it a follow-on to CERES. The two projects are working together and, as of spring 2021, have begun to hold joint STMs.

The University of Colorado Boulder's Laboratory of Atmospheric and Space Physics (CU, LASP; hereinafter referred to as LASP) will build Libera. At the Spring 2021 meeting, **Peter Pilewskie** [LASP—*Libera PI*] provided an update on the instrument's progress. He also announced that Libera had successfully completed its System Readiness Review. Pilewskie then provided in outline form the unique science data products that the Libera team is planning to produce.

Dave Harber [LASP] highlighted the difference between the CERES and Libera instruments. For example, Libera uses closed-loop electrical substitution radiometers that maintain constant detector temperature by adjusting the power to the vertically aligned carbon nanotube (VACNT) optical absorber detector. This permits higher accuracy, improved stability, and easier manufacturability. He also explained that Libera will be more responsive than CERES to the signal being received. There is a new internal calibration source being used for Libera that adds spectral tracking for the SW channel. The addition of the split shortwave channel should provide insight into SW scattering and absorbing processes. Harber also presented the calibration plan for the instrument.

Sebastian Schmidt [LASP] explained how a 550-nm, wide-field-of-view (WFOV) camera will be incorporated into the design of Libera as an independent means of scene identification to be used for angular-distribution-model development for the split solar channel without needing to go into rotating azimuth plane scan (RAPS) mode. It will also serve as a step toward a self-contained observation system. There were two CERES instruments included on Terra (FM-1 and -2) and Aqua (FM-3 and -4) to allow one of them to operate in RAPS mode to obtain the necessary observations of looking at a single point at various view and relative azimuth angles needed to develop the angular distribution models (ADMs). The other instrument remained in crosstrack mode to obtain the necessary observations for a climate product. Even though ADMs are sensitive to the cloud properties used in their development, since there is only one CERES instrument on Suomi NPP (FM-5), it was not placed into RAPS mode until the CERES instrument on NOAA-20 (FM-6) was available to provide the crosstrack observation in the afternoon orbit. Because Libera will not require RAPS mode, ADMs can be developed sooner.

Jake Gristey [Cooperative Institute for Research in Environmental Science (CIRES)] outlined the steps that will be used in the split shortwave irradiance inversion. The plan is to take advantage of the WFOV camera to obtain dense angular sampling with each observation and take advantage of azimuthal scan when available to constrain the results. Initially, the team will focus on the 12 Earth Radiation Budget Experiment (ERBE) scene types based on imaging at Libera scales.[11] Later work will use machine learning to derive ADMs for CERES-like scene types.

Maria Hakuba [NASA/Jet Propulsion Laboratory (JPL)] described the science objective of the Libera shortwave split channel, with regard to measuring SW radiance below 700 nm. This includes better understanding of the albedo symmetry across hemispheres, for which Coupled Model Intercomparison Project 6 (CMIP6)[12] models showed a large range of variability. The albedo symmetry is a result of different processes in each hemisphere, with different near-infrared to visible ratios between liquid and ice clouds and amounts of atmospheric water vapor absorption.

Invited Science Presentations

There were two invited presentations for both the Fall 2020 and Spring 2021 meetings, the summaries of which appear here in chronological order. Modeling community members are the primary users of CERES

[10] 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 *www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth*.

[11] A description of the ERBE Scene Types, developed without the benefit of imager information, can be downloaded from *go.nasa.gov/3wuvqlp*.

[12] CMIP is a standard experimental framework for studying the output of coupled atmosphere–ocean general circulation models, allowing assessment of model strengths and weaknesses and contributing to the development of future models. There have been six CMIP phases to date, with CMIP5 and CMIP6 mentioned in this article. Learn more at *www.wcrp-climate.org/wgcm-cmip*.

radiation and flux data to validate and analyze models. Three of the presentations were given by modelers, while the fourth provided information on instruments measuring the ocean heat content (OHC).

Aaron Donohoe [University of Washington, Applied Physics Laboratory (APL)] described sea-ice-albedo feedback (SIAF), which is the product of the ice sensitivity (IS) and radiative sensitivity (RS), as seen in observations and models. The IS is the change in surface albedo as the planet warms and RS is how much the TOA radiation changes as the surface albedo changes. The Arctic observed SIAF of 0.16 W/m^2 K is slightly higher than the calculation using CMIP5 ensemble averages (0.12 W/m^2 K). This calculation is not sensitive to the variation in RS from the individual model—with the majority of the spread coming from IS differences. Donohoe also investigated the meridional heat transport (MHT) due to the difference in absorbed solar radiation (ASR) and outgoing longwave radiation (OLR). The maximum MHT can differ by as much as 20% between CMIP5 simulations of preindustrial climate, due to cloud distribution and cloud properties. Ocean heat transport is too weak in all models, and the distribution of atmospheric heat transport (AHT) between meridional overturning circulation (MOC), transient eddies (TE), and stationary eddies (SE) is not consistent with observations. The Northern Hemisphere midlatitude observed TE is larger than the model values, but SE is weaker in boreal winter, and model TE makes a modest contribution in the tropics whereas observations contribute AHT in the tropics to MOC.

Steven Pawson [GMAO] presented the GMAO's plan to upgrade their products over the next five years. A special run of the Goddard Earth Observing System Model (GEOS) is used for meteorology during CERES product production; the GEOS Forward Processing–Instrument Team (FP-IT) low-latency product is used for the Fast Longwave And Shortwave Radiative Fluxes (FLASHFlux) near-real-time subset of CERES products. The GEOS Reanalysis for early 21st Century (GEOS-R21C) will be a post-Modern-Era Retrospective analysis for Research and Applications (MERRA) product that will improve clouds, precipitation, and surface energy balance through enhanced use of observations. It will bridge the gap from NASA's Earth Observing System (EOS) observations to the post-EOS era. Their target for GEOS-R21C is a 25-km resolution system that uses hybrid 4D-EnVar assimilation. Upgrades to the physics package include the Rapid Radiative Transfer Model for Global Climate Models (GCMs) [RRTMG] and improved representation of cloud, ice, and liquid effective radii, Grell-Freitas convective parameterization, and improved physical treatments of soil moisture diffusion and surface thermodynamics. Pawson showed more representative fluxes in the Artic with this version of the model than MERRA-2 when compared with CERES EBAF 4.1 data. The GEOS-IT will assume the GEOS-FP IT role. This version will also take advantage of improvements from new observations, but retain the 50-km (~31-mi) resolution and the three-dimensional variational (3DVar) assimilation, due to runtime and data volumes.

Tim Myers [Lawrence Livermore National Laboratory] explored constraints on low-cloud feedback to cloud radiative effect (CRE) from observed climate variability. Meteorological cloud radiative kernels are used to determine how changes in six cloud-controlling factors are reflected in changes to low-cloud radiative fluxes. These relationships are then applied to the change in the controlling factors predicted by climate models. The two dominant components are the increase in sea surface temperature (SST) that produces strong positive feedback in the eastern ocean basins and estimated inversion strength (EIS) that causes positive feedback in midlatitudes and negative feedback in the tropics. When the controlling factors are used with CMIPS6 output, an equilibrium climate sensitivity (ECS) near 3 K is implied.

Gregory Johnson [NOAA Pacific Marine Environmental Laboratory] provided a history of ocean heat content measurements and the observed variations in accuracy and sampling frequency. Significant improvement in depth and frequency measurements did not occur until the 1960s. Consistent measurement down to 2 km (~1.2 mi) did not occur until the *Argo*[13] buoys became available in 2005. CERES and the Argo system are complementary but independent measurement systems, and both show correlated interannual variation in the Earth's energy storage. They both find statistically significant and similar acceleration in the warming rate with approximate doubling from 2005 to 2019. A new set of buoys, Deep Argo (*argo.ucsd.edu/expansion/deep-argo-mission*), provides temperature and salinity measurements down to 6 km (~3.7 mi). Currently, the Deep Argo buoys are only operational in regional pilot arrays, but a global network could reduce the uncertainties in heat gain by a factor of five.

Contributed Science Presentations

This section of the two meetings contained a total of 38 presentations that provided information on:

- impacts of COVID-19 and meteorology on aerosol direct radiative effects over China;
- increasing radiative forcing being detected in CERES observations and models;
- measuring cloud and albedo radiation feedback in observations and models, especially in the Arctic and the Tropics;
- improvements in CERES algorithms and products;

[13] Argo is an international program that collects data on the ocean using a fleet of robotic drifting buoys. For more information, visit *www.aoml.noaa.gov/phod/argo*.

- status of updates on European missions including GERB and the upcoming Absolute Solar Terrestrial Radiation Imbalance Explorer (ASTERIX) and Sun-earth IMBAlance (SIMBA) CubeSats;
- explanation of the CrIS Fusion Products;
- the debate over Earth albedo hemispheric symmetry;
- impacts on CERES GMAO assimilation due to instrument loss; and
- validation efforts from field campaigns and independent measurements.

The presentations below are selected highlights from the Fall and Spring meetings.

Seung-Hee Ham [LaRC/SSAI] showed preliminary result of the Release D1 (RelD1) CERES, Cloud-Aerosol Lidar and Infrared Pathfinder Satellite (CALIPSO), CloudSat, and MODIS product during the fall meeting.[14] The new release will use latter versions of CALIPSO Version 4 and CloudSat Release 5 and added information from the CloudSat and CALIPSO Ice Cloud Property Product (2C-ICE) product. Ham explained a new method of creating the cloud profile. These changes have reduced the difference of TOA SW flux between observations and simulations, from 7.3 W/m^2 in the previous version to -0.44 W/m^2, and have reduced the daytime TOA LW difference from -7.5 W/m^2 to -2.5 W/m^2.

Norman Loeb used CERES EBAF observations to analyze Earth's energy imbalance (EEI) trend over the 20-year CERES record. Nearly half the increase in ASR is offset by increased loss of energy through the OLR, yielding a net heating trend of 0.37 W/m^2 per decade, or 0.74 W/m^2 in total changes for the period between March 2000 and February 2020. As mentioned earlier, this is consistent with the increasing planetary heat uptake, as derived from Argo and altimeter data. The analysis then used the partial radiative perturbation method to determine what are the major noncloud contributions to the trend—see **Figure**. The decreases in cloud amount and sea ice contribute the most to the positive ASR trend (62% and 27%, respectively); the increase in global mean temperature is the main reason for the overall increase in LW emission to space, with some reduction from the presence of water vapor and greenhouse gases.

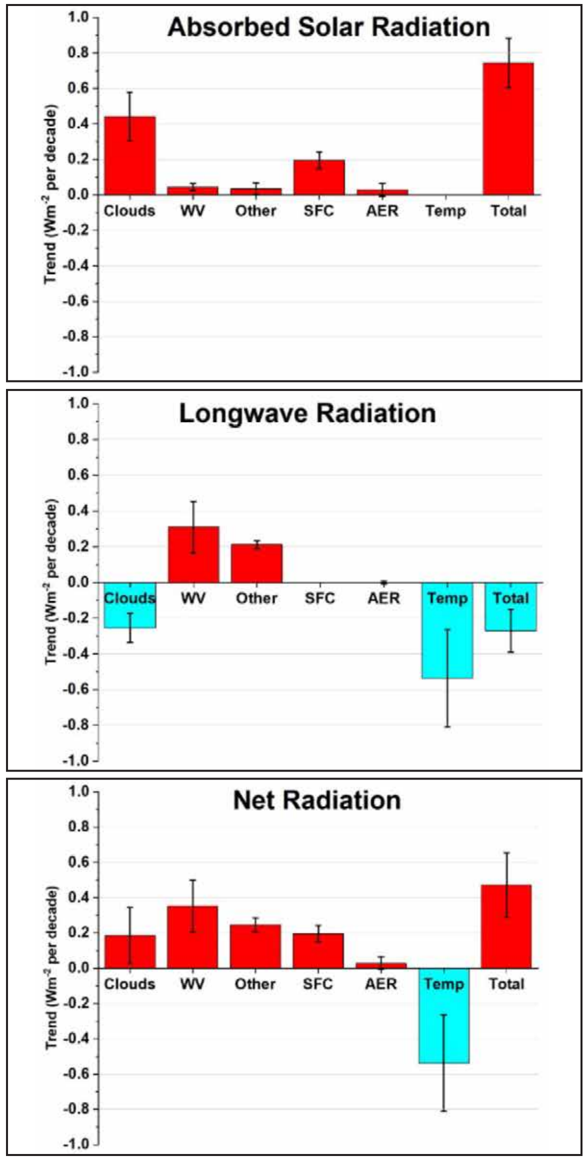

Figure. The trend in the Earth's energy imbalance as derived using CERES data from March 2000 through February 2020, with contributions allocated between changes in clouds, water vapor (WV), greenhouse gases (Other), surface albedo (SFC), aerosol (AER), and skin temperature and atmospheric profile temperature (Temp). On all three of the graphs, positive values indicate heat gain within Earth's systems from the phenomenon indicated; negative values indicate loss of absorbed solar radiation (ASR) [*top*], negative outgoing longwave radiation (OLR) [*middle*], and net (i.e., ASR minus OLR) [*bottom*] from Earth's surface, respectively. The trends are 0.68 W/m^2 per decade for ASR, -0.31 W/m^2 per decade for OLR, and 0.37 W/m^2 per decade for net. **Image credit:** Norman Loeb

Conclusion

Despite an ongoing pandemic, the CERES Science Team had another productive year of research. Multiple presentations at both the Fall 2020 and Spring 2021 meetings provided insight as to how the Arctic and low-cloud feedback on CRE is still not consistently handled by general circulation models. Several data providers discussed their efforts to improve their respective products. Other presentations covered results from the team's efforts in handling the impending loss of Terra, validating the current CERES data products, and efforts toward preparing for the next edition of products.

The next CERES STM will be held virtually, October 12-14, 2021, once again hosted by Norm Loeb at LaRC. ■

[14] CALIPSO, CloudSat, and Aqua are NASA satellites in the same afternoon orbit referred to as the A-Train. See *atrain.nasa.gov* for additional information.

Major Ocean-Observing Satellite Starts Providing Science Data

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EDITOR'S NOTE: This article is taken from *nasa.gov*. While this material contains essentially the same content as the original release, it has been rearranged and wordsmithed for the context of *The Earth Observer*.

Sentinel-6 Michael Freilich, the latest spacecraft to monitor sea surface height, has released its first science measurements to users—see **Figure**.[1]

After six months of check-out and calibration in orbit, the Sentinel-6 Michael Freilich satellite made its first two data streams available to the public on June 22.[2] It launched from Vandenberg Air Force Base in California on November 21, 2020, and is a U.S.–European collaboration to measure sea surface height and other key ocean features, such as ocean surface wind speed and wave height (*www.nasa.gov/sentinel-6*).

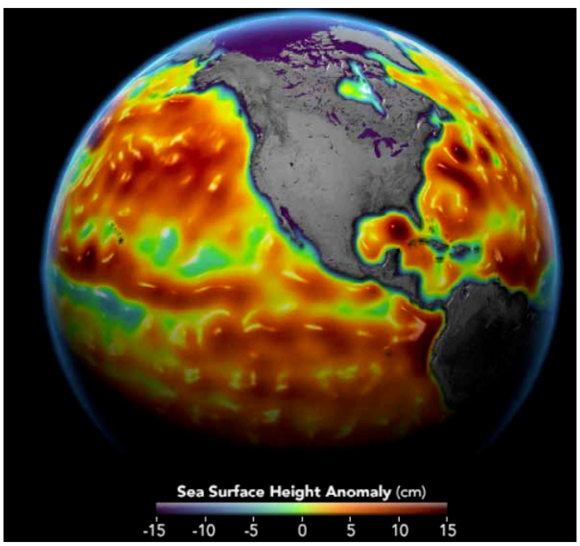

Figure. The map above shows sea surface height anomalies (3.5 cm accuracy) as measured by Sentinel-6 Michael Freilich's radar altimeter between June 5–15, 2021. Red and orange shades show regions where sea level was higher than normal. Blue and purple shades show regions where it was lower than normal. **Image credit:** NASA Earth Observatory

One of the sea surface height data streams that will be released is accurate to 2.3 in (5.8 cm) and will be available within hours of when the instruments aboard Sentinel-6 Michael Freilich collect it. A second stream of data, accurate to 1.4 in (3.5 cm), will be released two days after collection. The difference in when the products become available balances accuracy with delivery timeliness for tasks like forecasting the weather and helping to monitor the formation of hurricanes. More datasets, which will be accurate to about 1.2 in (2.9 cm), are slated for distribution later this year and are intended for research activities and climate science including tracking global mean sea level rise.

The satellite, named after former NASA Earth Science Division Director Michael Freilich, collects its measurements for about 90% of the world's ocean. It is one of two satellites that compose the Copernicus Sentinel-6/Jason-Continuity of Service (CS) mission. The second satellite, Sentinel-6B, is slated for launch in 2025. Together, they are the latest in a series of spacecraft starting with TOPEX/Poseidon in 1992 and continuing with the Jason series of satellites that have been gathering precise ocean height measurements for nearly 30 years.

Shortly after launch, Sentinel-6 Michael Freilich moved into position, trailing the current reference sea level satellite Jason-3 by 30 seconds. Scientists and engineers then spent time cross calibrating the data collected by both satellites to ensure the continuity of measurements between the two. Once they are assured of the data quality, Sentinel-6 Michael Freilich will then become the primary sea level satellite.

"It's a relief knowing that the satellite is working and that the data look good," said **Josh Willis** [NASA/Jet Propulsion Laboratory—*Sentinel 6 Michael Freilich Project Scientist*]. "Several months from now, Sentinel-6 Michael Freilich will take over for its predecessor, Jason-3, and this data release is the first step in that process."

Keeping an Eye on Rising Seas

The ocean absorbs more than 90% of the heat trapped in the Earth system by increasing concentrations of greenhouse gases, which causes seawater to expand and sea level to rise. Monitoring ocean height is important because it helps forecasters predict things, including ocean currents and potential hurricane strength.

"These initial data show that Sentinel-6 Michael Freilich is an amazing new tool that will help to improve marine and weather forecasts," said **Eric Leuliette** [National Oceanic and Atmospheric Administration—*Program and Project Scientist*]. "In a changing climate, it's a great achievement that these data are ready for release."

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[1] To learn more about the image and download a JPEG, visit *go.nasa.gov/3wUDuNh*.
[2] To access data from Sentinel-6 Michael Freilich, visit *podaac.jpl.nasa.gov* or *go.nasa.gov/36F8DsN*.

Pathfinder Satellite Paves Way for Constellation of Tropical-Storm Observers

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EDITOR'S NOTE: This article is taken from *nasa.gov*. While this material contains essentially the same content as the original release, it has been rearranged and wordsmithed for the context of *The Earth Observer*.

The 2020 Atlantic hurricane season was one of the most brutal on record, producing an unprecedented 30 named storms. What's more, a record-tying 10 of those storms were characterized as rapidly intensifying—some throttling up by 100 mph (161 kph) in under two days.

To bring more data to forecasters and have a more consistent watch over Earth's tropical belt where these storms form, NASA has launched a test satellite, or *pathfinder*, ahead of a constellation of six weather satellites called TROPICS, or Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats.[1] Planned for launch in 2022, the TROPICS satellites will work together to provide near-hourly microwave observations of a storm's precipitation, temperature, and humidity—a revisit time for these measurements not currently possible with other satellites.

"As a lifelong Floridian, I've seen firsthand the devastating impact that hurricanes can have on our communities. And as climate change is making hurricanes even stronger, it's more important than ever that NASA and our partners invest in missions like TROPICS to better track and understand extreme weather," said **NASA Administrator Sen. Bill Nelson**. "NASA's innovation is strengthening data models that help scientists improve storm forecasting and understand the factors that feed these monster storms. TROPICS will help to do just that and we look forward to next year's launch of the TROPICS satellite constellation."

"TROPICS is the beginning of a new era. This mission will be among the first to use a constellation of small satellites for these types of global, rapid-revisit views of tropical storms," said **Scott Braun** [NASA's Goddard Space Flight Center—*TROPICS Project Scientist*].

Since tropical cyclones and hurricanes can change rapidly as they travel across the ocean, the increased observations from the TROPICS satellites will not only advance the science of understanding storm intensity, they also may improve intensity forecasts.

"The project holds great promise to boost the National Oceanic and Atmospheric Administration's (NOAA's) steady improvements in weather and hurricane forecasts by feeding new environmental data into our world-class numerical weather prediction models," said **Frank Marks** [NOAA's Atlantic Oceanographic and Meteorological Laboratory—*Director of the Hurricane Research Division*]. After all six satellites are launched and positioned in 2022, Marks noted that "this new constellation will provide high frequency temperature and humidity soundings as we seek to learn how hurricanes interact with the surrounding temperature and moisture environment—key data that could improve hurricane intensity forecasts."

Figure. The TROPICS Pathfinder satellite, pictured above, was launched on June 30, 2021. The satellite body measures approximately 10 cm x 10 cm x 36 cm (~4 in x 4 in x 14 in) and is identical to the six additional satellites that will be launched into the constellation in 2022. The golden cube at the top is the microwave radiometer, which measures the precipitation, temperature, and humidity inside tropical storms. **Image credit:** Blue Canyon Technologies

The launch of a pathfinder satellite—a seventh identical copy of the TROPICS smallsats—is a critical step that will enable full testing of the technology, communication systems, data processing, and data flow to application users in advance of the constellation's launch. This will allow time for adjustments to the ground system and data products, helping ensure the success of the TROPICS mission—see **Figure**.

"The TROPICS Pathfinder satellite is similar to a screening before the opening night of a big show," said **Nicholas Zorn** [Massachusetts Institute of Technology

[1] The TROPICS Pathfinder was part of the payload on SpaceX's Transporter 2 Falcon 9 mission, which launched June 30, 2021, at 3:31 PM Eastern Daylight Time from Cape Canaveral.

(MIT), Lincoln Laboratory—*TROPICS Pathfinder Program Manager*]. "Its mission is a real-world, end-to-end test, from environmental verification through integration, launch, ground communications, commissioning, calibration, operations, and science data processing. Any areas for improvement identified along the way can be reinforced before the constellation launches."

Six years ago, **William Blackwell** [MIT Lincoln Laboratory—*TROPICS Principal Investigator*] submitted TROPICS as a proposal to NASA's Earth Venture Instrument competition series and was awarded funding. The Earth Venture Instrument program calls for innovative, science-driven, cost-effective missions to solve pressing issues related to Earth science.

Aboard each TROPICS small satellite is an instrument called a microwave radiometer, which detects temperature, moisture, and rainfall in the atmosphere. On current weather satellites, microwave radiometers are about the size of a washing machine. On TROPICS' small satellites the radiometers are about the size of a coffee mug.

Microwave radiometers work by detecting the radiation naturally emitted by oxygen and water vapor in the air. The TROPICS instrument measures these emissions via an antenna spinning at one end of the satellite. The antenna listens in at 12 microwave channels between 90 to 205 GHz, where the relevant emission signals are strongest. These channels capture signals at different heights throughout the lowest layer of the atmosphere, or troposphere, where most weather we experience occurs.

By flying the TROPICS radiometers at lower altitude and detecting fewer channels than their larger counterparts in the channels they do carry, the radiometers deliver comparable performance.

Miniaturizing the microwave radiometer has been an incremental process over the last 10 years for Blackwell and his team, spurred by the invention of *CubeSats*, satellites the size of a loaf of bread that are often economical to launch.[2] TROPICS builds on Blackwell and his team's 2018 success in launching the first microwave radiometer on a CubeSat to collect atmospheric profiling data. The instrument aboard the TROPICS' six satellites has been upgraded to provide improved sensitivity, resolution, and reliability and will make more targeted and rapid weather observations.

"These storms affect a lot of people, and we expect that with the increased observations over a single storm from TROPICS, we will be able to improve forecasts, which translates to helping people get to safety sooner, protect property, and overall enhance the national economy," Blackwell says, looking ahead to the full constellation launch next year. "It is amazing technology that we have proven out that allows us to maximize the science from the instrument's size factor. To pull this off has taken contributions of so many people." ■

[2] To learn more, see "CubeSats and Their Role in NASA's Earth Science Investigations," in the November–December 2020 issue of *The Earth Observer* [**Volume 32**, **Issue 5**, pp. 5–17—*go.nasa.gov/3tmwAig*].

Major Ocean-Observing Satellite Starts Providing Science Data

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Julia Figa Saldana [European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)—*Ocean Altimetry Programme Manager*] added that the operational release of the first data streams from this unique ocean altimetry mission was a significant milestone at the start of the Atlantic hurricane season.

"The altimetry data are now being processed at EUMETSAT headquarters in Darmstadt, Germany, from where the satellite is also being controlled, and released to ocean and weather forecasting data users around the world for their operational usage," Saldana said.

Scientists also anticipate using the data to gauge how fast sea levels are rising because of climate change. The expansion of warm seawater accounts for about one-third of modern-day sea level rise, while meltwater from glaciers and ice sheets accounts for the rest. The rate at which the ocean is rising has accelerated over the past two decades, and researchers expect it to speed up more in the years to come. Sea level rise will change coastlines and increase flooding from tides and storms. To better understand how rising seas will impact humanity, researchers need long climate records—something Sentinel-6 Michael Freilich will help provide. ■

NASA Maps Air Quality in Ozone Hot Spot

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EDITOR'S NOTE: This article is taken from *nasa.gov*. While this material contains essentially the same content as the original release, it has been rearranged and wordsmithed for the context of *The Earth Observer*.

Scientists are flying an airborne campaign out of NASA's Langley Research Center (LaRC) beginning in June 2021, to contribute to a joint U.S.–Canadian study on air quality in a region with high surface ozone levels.

A community-organized effort led by the Michigan Department of Environment, Great Lakes, and Energy named Michigan Ontario Ozone Source Experiment (MOOSE) is targeting the border region that's home to Detroit on the U.S. side and Windsor, Ontario, in Canada. The southeast Michigan region has ozone levels higher than the U.S. federal standard and elevated ozone also exists across the border in southern Ontario.

High surface ozone levels are harmful to human health, especially in children, older adults, and people with asthma. They tend to occur near urban regions in the summer months with high temperatures and strong sunlight, which both accelerate ozone formation. This issue is more complex when emissions occur near large water bodies where pollutants can be trapped near the surface and then are transported by breezes that result from the large temperature differences between water and land. Detroit and Windsor are separated by the Detroit River, which runs between Lake St. Clair to the north and Lake Erie to the south—see **Photo**.

The MOOSE study includes partners from a number of agencies, both state and federal, as well as organizations and academic institutes from both the U.S. and Canada. Measurements will be taken on land and in the air. Scientists hope to better characterize causes of elevated ozone levels in the region, the strength of emissions from sources such as vehicular traffic, power plants, and other industrial processes burning fossil fuels, which all will help identify potential strategies for improving ozone air quality.

"From NASA's vantage point in space, we have the unique ability to monitor Earth's air pollution and contribute to studies that help researchers shine a light on the human health impacts of air quality," said **NASA Administrator Sen. Bill Nelson**. "NASA's research is essential to the future of the planet and improving life here on Earth. The air quality data we and our partners collect now will help NASA carry out that mission, bringing about changes that will benefit people living in vulnerable and often underserved areas."

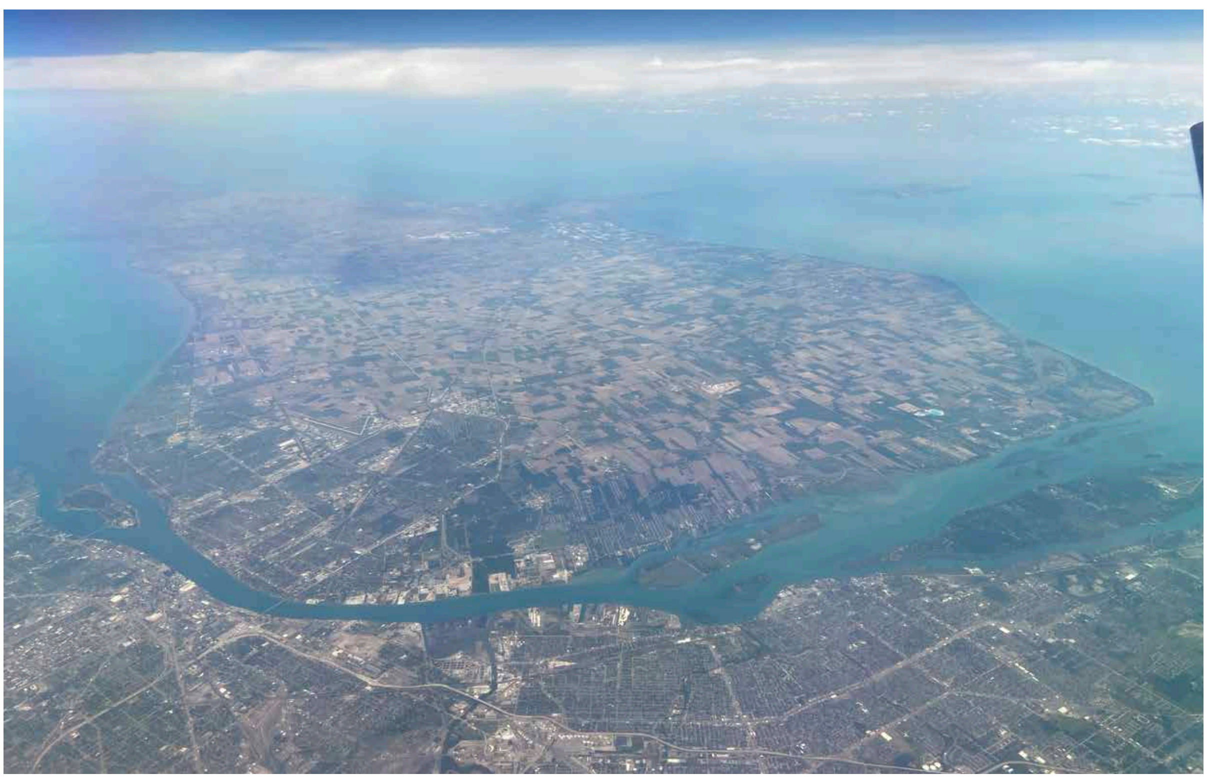

Photo. A view of the MOOSE study region from the Langley C-20B Gulfstream III. On the far side is the city of Windsor, Ontario, in Canada. Detroit, MI, is in the foreground, with downtown Detroit on the lower left. The Detroit River runs between the two cities. **Credit:** NASA/Kenny Christian

NASA scientists are aiming to conduct flights during six days on Langley's C-20B Gulfstream III (G-III) aircraft carrying two instruments from NASA's Goddard Space Flight Center (GSFC). One instrument, called the Cloud Physics Lidar, uses a laser to make measurements of clouds and tiny atmospheric particles called aerosols. The G-III also carries the GEOstationary Coastal and Air Pollution Events (GEO-CAPE) Airborne Simulator [GCAS], an instrument that measures proxies of ozone precursors such as nitrogen dioxide and formaldehyde. The GCAS instrument's measurements will provide a top-down view of emission hotspots and the evolution of these trace-gases downwind of the source.

"This is the first time these instruments have flown on a G-III," said **Laura Judd** [LaRC], who is leading NASA's participation in the study. "Evolving from slower, shorter range aircraft that we've flown on in the past field studies to these jets for our airborne measurements is an advancement through the increase in the range we can fly in a day, which allows us to do repeated mapping over a larger area to observe changes in pollution throughout the day."

GCAS is a test bed for an upcoming NASA mission called Tropospheric Emissions: Monitoring of Pollution (TEMPO)—the first geostationary air quality mission over North America. Scheduled to launch in 2022, TEMPO will make hourly measurements of air pollution over an area that will reach from Puerto Rico and Mexico to northern Canada, and from the Atlantic to the Pacific, encompassing the contiguous U.S. It will also form part of a virtual air quality satellite constellation looking at pollution around the Northern Hemisphere. The other members of this constellation include South Korea's Korean MP-GEOSAT, which launched in 2020 and carries the Geostationary Environment Monitoring Spectrometer (GEMS), and Europe's Sentinel-4, currently scheduled to launch in 2023, which will carry the Ultraviolet-Visible-Near infrared imaging spectrometer (UVN).[1]

"Our airborne measurements not only help us and our partners prepare for using TEMPO data, but also provide an unseen perspective on emissions and can even identify if socioeconomic disparities in air quality exposure exist in these polluted metropolitan areas investigated," said Judd.

MOOSE is one of several regional air quality studies in which NASA has participated in recent years. Other studies have looked at elevated ozone levels on the Lake Michigan coast, around the Long Island Sound, and in both the southern and northern parts of the Chesapeake Bay. Later this summer, Judd and **John Sullivan** [GSFC] will be co-principal investigators for Tracking Aerosol Convection interactions ExpeRiment-Air Quality (TRACER-AQ), a study looking at air quality issues in Houston, TX. TRACER-AQ is tied to the Department of Energy's TRACER study, which will look at the impact of aerosols on microphysical processes within convective clouds near the region. ■

[1] TEMPO and the virtual air quality constellation were discussed in "NASA Ups the TEMPO on Air Quality Measurements" in the March–April 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 2**, pp. 10–15—*go.nasa.gov/2WGStuX*]. More information on TEMPO can be found at *tempo.si.edu/index.html*.

NASA Earth Science in the News

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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*.

Pacific Northwest Heat Wave Would Have Been "Virtually Impossible" Without Climate Change, Experts Say, July 8, *cbsnews.com*. In June 2021 the Pacific Northwest—a place normally known for its cool and wet climate—endured the most extraordinary heat wave ever observed there in modern times. Even seasoned meteorologists could not believe what they were seeing as seemingly impossible heat persisted day after day. Portland, OR, climbed to 116 °F (~46 °C). Lytton, Canada, broke that nation's all-time record three days in a row, topping out at 121 °F (~49 °C). The extremity of the heat wasn't just unusual—it would have been "virtually impossible without human-caused climate change," according to a new analysis by 27 climate scientists from the World Weather Attribution network.[1] While there are various and complex factors that came together to magnify this specific event, climate scientist **Peter Kalmus** [NASA/Jet Propulsion Laboratory (JPL)] says the extreme heat wave is evidence of our escalating climate crisis. "Climate impacts including extreme heat, fire, and drought are hitting us now. They are like punches to our civilization and they will keep coming both faster and stronger. These and other impacts will keep intensifying so long as we burn fossil fuels," said Kalmus. The authors of the study agree and say the takeaway is simple: "Until overall greenhouse gas emissions are halted, global temperatures will continue to increase and events like these will become more frequent." Kalmus takes it a step further, telling CBS News, "If you think about it, there's no way to adequately prepare for these impacts. The only reasonable option is to do whatever it takes to completely end the fossil fuel industry in the short term. We need strong policies, but we also need the public to realize what an emergency this is in order to get those policies."

Rising Seas, Lunar Wobble to Increase U.S. Coastal Flooding in 2030s, NASA Says, July 7, *upi.com*. Coastal flooding in the U.S. is expected to worsen in the 2030s due to a combination of rising sea levels and an expected wobble in the moon's orbit, according to a NASA study released July 7, 2021.[2] The agency's Sea Level Change Science Team from the University of Hawaii made its predictions based on the Moon's typical 18.6-year precessional cycle. During half of that cycle, high tides are lower than normal and low tides are higher than normal. During the other half, a wobble causes the tides to be more extreme—high tides are higher and low tides are lower. The Earth is currently in its amplified tide phase of the lunar cycle, but increased global warming and sea level rise are expected to increase the impact of the tides during the next cycle. "Low-lying areas near sea level are increasingly at risk and suffering due to the increased flooding, and it will only get worse," **NASA Administrator Sen. Bill Nelson** said in a statement. "The combination of the moon's gravitational pull, rising sea levels, and climate change will continue to exacerbate coastal flooding on our coastlines and across the world." Far northern coasts, such as those in Alaska, will be spared because the land there is rising due to geological processes.

NASA Says Earth Now Trapping 'Unprecedented' Amount of Heat—And It's Doubled in just 15 Years, July 17, *thehill.com*. A joint study between NASA and the National Oceanic and Atmospheric Administration (NOAA) reveals that more energy in the form of heat has been entering and staying in Earth's atmosphere than leaving, adding to the large body of scientific literature confirming that temperatures on the planet are rising. This generates warmer waters, like the ocean, and hot drought-like conditions. In the study, published in the journal *Geophysical Research Letters*, scientists used indicator data from satellite sensors as well as ocean barges to estimate changes in atmospheric temperatures.[3] Other data that point to rising global temperatures include increases in emissions of greenhouse gases, namely methane and carbon dioxide, which make large contributions to the energy imbalance Earth is exhibiting. Scientists write that the imbalance in heat has doubled in the 14-year period from 2005 to 2019. "The trends we found were quite alarming in a sense," said **Norman Loeb** [NASA's

[1] To read more, visit *www.worldweatherattribution.org/western-north-american-extreme-heat-virtually-impossible-without-human-caused-climate-change*.

[2] To read the study, visit *go.nasa.gov/3hIeAdw*.

[3] To read the study, visit *agupubs.onlinelibrary.wiley.com/doi/10.1029/2021GL093047*.

Langley Research Center], lead author for the study and principal investigator for the Clouds and the Earth's Radiant Energy System (CERES) instrument. Loeb and his colleagues noted that cooler-than-average temperatures also contribute to the recorded energy imbalance in Earth's atmosphere. Some weather patterns, like the Pacific Decadal Oscillation, are naturally occurring and also exacerbate the effects of human-caused climate change. Thus, the excess heat coming into the Earth's atmosphere is likely a result of several factors. "It's likely a mix of anthropogenic forcing and internal variability," Loeb added. "And over this period, they're both causing warming, which leads to a fairly large change in Earth's energy imbalance. The magnitude of the increase is unprecedented." Either way, warmer temperatures and other changes in the climate system are to be expected. This comes as NASA separately notes that May 2021 is now tied for the sixth warmest May on record. This brought both lower rates of snow coverage and small Arctic sea ice coverage.

Researchers Harness a NASA Satellite to Track Microplastics in the Atlantic, June 27, *slashgear.com*. Researchers from the University of Michigan have devised a way to use data collected by NASA satellites to track the movement of tiny pieces of plastic in the Atlantic Ocean. The plastic they're tracking is known as *microplastics,* formed when plastic trash in the ocean begins to break down from a combination of the Sun's rays and the motion of ocean waves. Microplastics are harmful to marine ecosystems. Strong currents in the ocean mean that microplastics can migrate hundreds or thousands of miles away from the source of pollution, making it difficult to track and remove the material. The main source of information about the location of microplastics comes from fishers whose nets also unintentionally scoop up microplastics. However, researchers are now using a new technique that leverages data from the NASA Cyclone Global Navigation Satellite System (CYGNSS), a constellation of eight small satellites designed to measure wind speed above the ocean. While the satellites were initially designed to gather information about the strength of hurricanes, the radar data obtained to measure ocean roughness can be impacted by factors including wind speed and debris floating in the water. Researchers were able to work backward to look for places where the ocean was smoother than expected given the wind speed, which they associated with the presence of microplastics. Scientists found that microplastics indeed tended to be present in smoother waters, demonstrating that satellite data could be used as a tool to track the debris from space. With the new tool to track the plastics, scientists will be able to easily determine where the source of the pollution is coming from and potentially clean the ocean of such pollution. The study results were published in the *IEEE Transactions of Geoscience and Remote Sensing*.[4]

NASA Looks at Louisiana Delta System, Eyes Global Forecasts, June 29, *apnews.com*. In the Mississippi River Delta system erosion, sinking land, and sea rise from climate change have killed the Louisiana woods where a 41-year-old Native American chief played as a child. And yet not far away, middle-school students can stand on islands that emerged the year they were born. To understand such phenomena, NASA is using high-tech airborne systems along with boats and mud-slogging island work for a $15 million, five-year study of these adjacent areas of Louisiana, where one is hitched to a river and growing, and the other is disconnected and dying.[5] Scientists from NASA and a half-dozen universities from Boston to California aim to create computer models that can be used with satellite data to let countries around the world learn which parts of their dwindling deltas can be shored up and which are past hope. "If you have to choose between saving an area and losing another instead of losing everything, you want to know where to put your resources to work to save the livelihood of all the people who live there," said lead scientist **Marc Simard** [JPL]. ■

[4] To read the study, visit *ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9449485&tag=1*. To view an animation of the CYGNSS data tracking the microplastics, visit *www.youtube.com/watch?v=sQTGOU9LiJ0*.

[5] To learn more about this study, visit *deltax.jpl.nasa.gov*.

Earth Science Meeting and Workshop Calendar

NASA Community

September 13–15, 2021
NASA AIRS/Sounder Science Team Meeting, *virtual*

October 12–14, 2021
CERES Science Team Meeting, *virtual*

Global Science Community

December 13-17, 2021
AGU Fall Meeting, New Orleans, LA.
and online everywhere. *www.agu.org/Fall-Meeting*

January 24-27, 2022
AMS Annual Meeting, Houston, TX.
annual.ametsoc.org/index.cfm/2022

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Article submissions, contributions to the meeting calendar, and other suggestions for content are welcomed. Contributions to the calendars should contain date, location (if meeting in person), URL, and point of contact if applicable. Newsletter content is due on the weekday closest to the first 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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