Over Thirty Years Reporting on NASA's Earth Science Program

The Earth Observer

National Aeronautics and Space Administration

January – February 2020. Volume 32, Issue 1

Editor's Corner

Steve Platnick
EOS Senior Project Scientist

On January 21, 2020, a *Symposium on Earth Science and Applications from Space* took place at the National Academy of Sciences in Washington, DC to pay tribute to the career of **Michael Freilich**. As director of the Earth Science Division at NASA Headquarters from 2006–2019—and throughout nearly 40 years of ocean research—Freilich helped train and inspire the next generation of scientists and scientific leaders. Freilich, his wife, and other family members were in attendance.

Colleen Hartman [National Academy of Sciences, Engineering, and Medicine (NASEM)—*Space Studies and Aeronautics Engineering Board Director*], the former Deputy Center Director at GSFC, moderated the symposium. After opening remarks from **Marcia McNutt** [NASEM—*President*] and **Thomas Zurbuchen** [NASA Headquarters (HQ)—*Associate Administrator of the Science Mission Directorate (SMD)*], **Dudley Chelton** [Oregon State University] gave a moving keynote presentation, where he gave an overview of Freilich's life and career from his unique perspective as both his colleague and longtime friend. After this came remarks from **William "Bill" Gail** [Global Weather Corporation], who discussed the development of the two Earth Science Decadal Surveys [2007 and 2017], emphasizing the key role that Freilich played in overseeing the development and implementation of these guiding documents for Earth Science.

A significant portion of the day was given over to a series of eight presentations that concentrated on research areas in which Freilich was actively involved and/or played an important support role throughout his career. In addition, panel discussions emphasized lessons learned from their interactions with Freilich, international collaborations (which Freilich played a key role in enhancing during his NASA tenure), and new directions and innovations for future Earth science research and applications. The symposium was a fitting tribute to a man who had a profound impact on NASA's Earth Science program and the careers of numerous individuals. His legacy will continue to impact NASA Earth Science positively for many years to come. *The Earth Observer* plans a more comprehensive report on the symposium in an upcoming issue.

A week later, on January 28, 2020, there was a ceremony in the James Webb Auditorium at NASA HQ, during which it was announced that the partners on the upcoming ESA Copernicus Sentinel-6A/Jason Continuity of Service (CS) mission,[1] scheduled to launch later this year, have agreed to rename it "Sentinel-6 Michael Freilich." This is a distinguished honor (only one other NASA or NASA-sponsored mission has previously been named after a living person)[2] that recognizes the tremendous contributions that Freilich has made to the field of ocean

[1] The Sentinel-6 mission consists of two identical satellites; Sentinel-6A, now renamed Sentinel-6 Michael Freilich, and Sentinel-6B, which has a launch readiness date of 2025. Sentinel-6 partners include ESA, NASA, the European Commission, EUMETSAT, and NOAA, with support from CNES.
[2] The Parker Solar Probe (Heliophysics) is the other NASA mission that was named after someone still alive; it was named after Eugene Parker in 2017.

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NASA Associate Administrator of the Science Mission Directorate, **Thomas Zurbuchen** [*left*], makes closing remarks with **Michael Freilich** [*right*] at the conclusion of a renaming ceremony for the international ocean science satellite previously known as Sentinel-6A/Jason-CS, Tuesday, January 28, 2020, at NASA Headquarters. NASA and its European partners renamed the satellite "Sentinel-6 Michael Freilich" after the former director of NASA's Earth Science Division. Sentinel-6A Michael Freilich will observe and record global sea level changes and will be joined by an identical Sentinel-6B satellite slated to launch in 2025, for a total of ten years of targeted observations. **Photo credit**: Aubrey Gemignani [NASA]

In This Issue

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

science—and, in particular, the crucial role he played in the development of the Sentinel-6 mission. **NASA Administrator Jim Bridenstine** attended and gave opening remarks; **Thomas Zurbuchen** also spoke, as did representatives from NOAA and each of the international partners on Sentinel-6.

Michael Freilich spoke during the ceremony, accepting the honor with gratitude, noting that it really belongs to *everyone* involved in the Sentinel-6 mission—including thousands of scientists, engineers, and bureaucrats on both sides of the Atlantic. He said that "decadal scale trends in regional and global sea-level are perhaps the most robust evidence that Earth's climate is changing, and that's why *humanity*—not one agency, not one country, not one continent—but humanity has been monitoring global sea-level from space for more than 28 years." Sentinel-6 will build on the legacy begun by TOPEX-Poseidon in 1992 and continued by Jason-1, -2, and -3, up to the present. Freilich lauded the series of sea-level altimetry missions as a tremendous example of the power of international collaboration. He described the sea-level time series as "the longest—and most successful—multinational and intercontinental, collaborative Earth remote sensing endeavor that our species has achieved."

Turning now to other news from NASA Earth Science, on January 31, 2020, the Soil Moisture Active Passive (SMAP) mission celebrated the fifth anniversary of its launch. The SMAP measurement system consists of a radiometer (passive) and a synthetic aperture radar (active) operating with multiple polarizations in the L-band range. Although the radar failed in July 2015, the radiometer is operating nominally and continues to provide global mapping of soil moisture with accuracy, resolution, and coverage that exceeds the capability of other on-orbit systems.

SMAP data products have been used for a variety of science research and applications. They provide information on the status of surface soil moisture and vegetation water content conditions approximately every 1.5 days, which has enabled advances in understanding the impact that water storage changes on the land surface have on regional climate and vegetation/crop conditions. In addition, several national agencies continue to evaluate SMAP data for use in drought forecasting, including the Drought Mitigation Center at the University of Nebraska–Lincoln, which issues the weekly *U.S. Drought Monitor* that serves as the basis for drought disaster declarations and for determining low-interest loans or tax-deferral eligibility. Because SMAP soil moisture products are produced with lower latency than those from other sources, the U.S. Air Force's 557th Weather Wing can incorporate SMAP data into a number of their applications. SMAP soil moisture data products are also an effective predictor of how much precipitation becomes storm streamflow, knowledge of which is important for minimizing loss of life and property during flooding, as well as compensating for low streamflow conditions that accompany drought. Finally, USDA's National Agricultural Statistics Service and Foreign Agricultural Service soon plan to use SMAP data in their operational systems for estimating global crop conditions. SMAP data are available at *https://nsidc.org/data/smap/smap-data.html*.

Two other missions recently had their initial public data release. The Global Ecosystem Dynamics Investigation (GEDI) mission, launched to the ISS in late 2018, has begun monthly data deliveries to NASA's LP DAAC. Several months of data have already been delivered and are being staged by LP DAAC. GEDI science operations began in April 2019 and the data releases include Level-1B (L1B) Geolocated Waveform Data, L2A Elevation and Height Metrics Data, and L2B Canopy Cover and Vertical Profile Metrics Data.

Mounted on the Japanese Experiment Module–Exposed Facility (JEM-EF) of the ISS, GEDI (pronounced like the Jedi of *Star Wars* fame) surveys Earth's forests using its three lasers to construct detailed three-dimensional (3D) maps of forest canopy height and the distribution of branches and leaves in the forest.[3] By accurately measuring forests in 3D, GEDI data play an important role in understanding how much biomass and carbon forests store and how much they lose when disturbed—vital information for understanding Earth's carbon cycle and how it is changing. Data from the mission can also be used to study plant and animal habitats and biodiversity, and how these may change over time.

Also mounted on the ISS JEM-EF module, the Orbiting Carbon Observatory-3 (OCO-3) publicly released L1B data from its three solar reflectance spectrometers at the end of January. Launched to the ISS in May 2019, OCO-3 complements the column carbon dioxide (CO_2) measurements from the still-operational polar orbiting OCO-2 mission with diurnal daytime observations. OCO-3 also provides a unique pointing capability to provide targeted maps with areal coverage of 80×80 km for areas of interest (e.g., cities, volcanoes). The dataset begins in December 2019 and is distributed from the Goddard Earth Sciences Data and Information Services Center (GES DISC).

The combination of GEDI, OCO-3, and ECOSTRESS (also on JEM-EF) data will be used synergistically to better understand the Earth's biosphere and carbon cycle in a changing climate.

Meanwhile, NASA's *Operation IceBridge* made its final polar flights in November 2019.[4] As its name implies, these aircraft campaigns were implemented as a means of "bridging" the data gap between ICESat, which ended in 2009, and ICESat-2, which launched September 2018. The Operation IceBridge campaigns gathered data on the height, depth, thickness, flow, and change of sea ice, glaciers, and ice sheets. Altogether, more than 900 flights were flown over Greenland and Antarctica, and more than 150 over Alaska. While Operation IceBridge certainly accomplished its primary mission—it did much more. Operating for more than a decade, the mission opened the door to new ways of thinking about monitoring the polar regions, enabled numerous unexpected scientific discoveries, and brought new scientists and new data types into the fold. Turn to page 35 of this issue to read a summary of Operation IceBridge's accomplishments over its eleven years.

NASA's Land, Atmosphere Near real-time Capability for EOS (LANCE) celebrated its tenth anniversary in 2019. LANCE replaced the former Near Real Time Processing Effort that dated to 2002. LANCE provides access to more than 200 Near Real-Time (NRT) data products, along with the services and data distribution strategies, typically within three hours of the satellite observations. Now beginning its second decade, LANCE has become an integral tool that is used to protect lives and property globally. NASA successfully leverages existing systems to provide NRT data at little extra cost to the standard processing, search, and delivery systems. The systems, strategies, and services developed by LANCE scientists and engineers not only complement standard data products in the EOSDIS collection, but further enhance the value of these data. Turn to page 4 of this issue to read about the evolution of LANCE, its components, and its accomplishments.

Last but certainly not least, as it does every year, NASA had a large exhibit at the Fall Meeting of the American Geophysical Union (AGU), held December 9-13 in San Francisco, CA—which was AGU's Centennial meeting. The 2019 exhibit theme was "NASA Lights the Way," which centered on the release of NASA's new 200-page *Earth at Night* book—described on page 20 of this issue. The exhibit featured NASA's Hyperwall, a "NASA Lights the Way" LED back-lit display, and three interactive areas that represented science activities from the four NASA SMD divisions: Earth Science, Planetary Science, Heliophysics, and Astrophysics.

Also noteworthy at this year's Fall AGU were the events to commemorate the twentieth anniversary of NASA's Terra mission. These events were discussed in the Editorial of the November–December 2019 issue of *The Earth Observer*, and they are discussed on page 22 of this issue—in the AGU summary article. There is also a detailed review of Terra, with quotes from team leaders for each instrument, posted on the EOSDIS *Earthdata* website at *https://earthdata.nasa.gov/learn/articles/terra-at-20*. ■

[3] See the front cover of the May–June 2019 issue of *The Earth Observer* [**Volume 31**, **Issue 3**, p. 1] to view an example of GEDI data.

[4] While its polar flights concluded in 2019, Operation IceBridge will conduct one more series of flights over Alaska in 2020.

See page 43 for a list of undefined acronyms used in the Editorial and/or table of contents.

LANCE: A Decade of Achievement Providing Near Real-Time NASA Earth Observing Data

Diane Davies, Science Systems and Applications, Inc./Trigg-Davies Consulting Ltd., diane.k.davies@nasa.gov
Karen Michael, NASA's Goddard Space Flight Center, karen.a.michael@nasa.gov
Dawn Lowe, NASA's Goddard Space Flight Center/The Aerospace Corporation, dawn.r.lowe@nasa.gov
Chris Justice, University of Maryland, College Park, cjustice@umd.edu
Miguel Román, Universities Space Research Association, mroman@usra.edu
Josh Blumenfeld, NASA's Goddard Space Flight Center/ADNET Systems, Inc., joshua.c.blumenfeld@nasa.gov

As LANCE celebrates its tenth anniversary, it is a good time to look back on its accomplishments.

Introduction

Since 2009, NASA's Land, Atmosphere Near real-time Capability for EOS[1] (LANCE) has provided data and data products generally within three hours of satellite instrument observations. The more than 200 Near Real-Time (NRT) data products available through LANCE, along with the services and data distribution strategies developed by the LANCE team, have helped transform how Earth-observing data are used. As LANCE celebrates its tenth anniversary, it is a good time to look back on its accomplishments. This article describes the evolution of NASA's NRT capabilities, shows how these capabilities were incorporated into LANCE, provides an overview of the design of LANCE architecture, and highlights significant LANCE accomplishments in processing and providing NRT Earth science data in NASA's Earth Observing System Data and Information System (EOSDIS) collection to data users worldwide—see *What Do We Mean by Near Real-Time?* [2]

[1] EOS stands for NASA's Earth Observing System.
[2] For an online overview of LANCE milestones from its first decade, see "LANCE Top 10 at 10" at *https://earthdata.nasa.gov/learn/articles/lance-at-10*. Most of these are discussed in the narrative that follows.

What Do We Mean by Near Real-Time?

NASA's EOSDIS defines *data latency* as the elapsed time between imaging or satellite observation and the time data are available to the end user. More specifically, latency for a data granule (an individual data value that is part of a larger collection) is defined as the time taken from the midpoint between the start and end of acquisition of the data for that granule to the granule being ready online for users to download via network access. NRT, low latency, or expedited data all refer to data made available much faster than allowed by standard routine processing.

At a workshop titled "NASA Data for Time Sensitive Applications," held at NASA's Langley Research Center (LaRC) in Hampton, Virginia, September 27–29, 2016,[1] participants defined and agreed upon the terms for latency shown in the Table below. These were adopted by NASA's EOSDIS in May 2018.

Term	Latency	Purpose
Real-time	Less than 1 hour	These terms are often used to refer to data that are produced more rapidly than routine processing allows. They are used for a range of applied sciences, decision and tactical support, monitoring, and early warning of events.
Near real-time (NRT)	1 to 3 hours	
Low latency	3 to 24 hours	
Expedited	1 to 4 days	
Standard routine processing	Generally, 8 to 40 hours but up to 2 months for some higher-level products	Standard products provide an internally consistent, well-calibrated record of Earth's geophysical properties to support science and applications.

[1] To learn more read "Summary of the Workshop on Time Sensitive Applications of NASA Data" in the March–April 2017 issue of The Earth Observer [**Volume 29**, **Issue 2**, pp. 19–22—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/March%20April%202017%20color%20508.pdf#page=19*].

Early NASA Efforts at Providing NRT Data

The launch of NASA's Terra mission in December 1999 marked the start of a coordinated effort to create a long-term climate data record using instruments onboard multiple satellites. NASA's EOS data processing system—the EOSDIS Core System (ECS)—was built primarily to produce standard data products designed to facilitate scientific research and applications.[3]

In early 2000, shortly after Terra's instruments began collecting data, the National Oceanic and Atmospheric Administration (NOAA) installed a server at NASA's Goddard Space Flight Center (GSFC) that enabled NOAA to receive rate-buffered[4] (raw satellite) data directly from the Moderate Resolution Imaging Spectroradiometer (MODIS)[5] instrument shortly after an observation. This data stream was called the NOAA *bent-pipe feed*, since it bypassed the ECS to provide raw data directly to NOAA. While the ECS system was intended to serve the science community with a few days lag, the purpose of this bent-pipe feed was to serve NRT data to support NRT applications for NOAA and other users.

The bent-pipe feed came under NASA/NOAA/Department of Defense (DOD) coordination in 2001 as part of a concerted effort to provide NRT data from NASA EOS instruments. This effort, the Near Real-Time Processing Effort (NRTPE), became fully operational in 2002, and was the precursor to LANCE.

Evolving Data Processing Capabilities: From NRTPE to Rapid Response to LANCE

The NRTPE was established to provide data within three hours of a satellite observation from NASA EOS instruments to the military, weather agencies, and first responders to facilitate the observation and monitoring of dust storms, fires, severe weather, and similar phenomena.

The Near Real-Time Processing Effort (NRTPE) was established to provide data within three hours of a satellite observation from NASA EOS instruments to the military, weather agencies, and first responders to facilitate the observation and monitoring of dust storms, fires, severe weather, and similar phenomena.

Prior to formalizing the NRTPE and in response to the destructive 2000 wildfire season in the U.S. Northwest, the U.S. Forest Service (USFS) reached out to scientists at NASA and the University of Maryland's (UMD) Department of Geographical Sciences (then known as the Department of Geography) to request NRT data and imagery to support wildfire suppression and response.

Fulfilling this request would require significant reductions in data latency. For optimal utility, the USFS needed data and imagery within hours of satellite acquisition instead of the seven-day latency provided through the ECS. A team of scientists from UMD, GSFC, and USFS assembled a series of customized images to demonstrate the significant contribution that NRT MODIS imagery could make to wildfire suppression and emergency rehabilitation. This effort was called *MODIS Rapid Response*, and was formally established in 2001.[6]

The team initially focused on providing NRT fire-detection data from MODIS on Terra to the USFS Remote Sensing Applications Center and the National Interagency Fire Center. The initial Rapid Response imagery was in a swath-based, nongeoreferenced format covering only North America.

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[3] To learn more about the evolution of EOSDIS, see "EOS Data and Information System: Where We Were and Where We Are, Parts I and II" in the July–August 2009 and September–October 2009 issues of *The Earth Observer* [**Volume 21**, **Issue 4**, pp.4–10 and **Issue 5**, pp. 8-14. Both of these articles were included in the "Perspectives on EOS" Special Issue of *The Earth Observer*, pp. 27-40—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Perspectives_EOS.pdf#page=27*.

[4] Rate Buffered Data contain data captured in a single spacecraft contact session that is sorted, processed, and delivered in an expedited manner.

[5] MODIS flies onboard NASA's Terra and Aqua Earth-observing satellites.

[6] To learn more read "MODIS Land Rapid Response: Operational Use of Terra Data for USFS Wildfire Management" in the September–October 2001 issue of *The Earth Observer* [**Volume 13**, **Issue 5**, pp. 8-14—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Sept_Oct01.pdf#page=8*].

By 2007 Rapid Response was producing global data, and had incorporated data and imagery from the MODIS instrument onboard NASA's Aqua Earth-observing satellite, launched in 2002. Some of the most valuable Rapid Response products included imagery based on the MODIS Corrected Reflectance algorithm, which provides *true-color* (i.e., natural-looking) images by removing gross atmospheric effects, such as Rayleigh scattering, from MODIS bands 1 through 7.

As the Rapid Response capability to provide imagery and information became more widely known, news organizations began requesting custom georeferenced images for large, newsworthy events—see examples in **Figure 1**.

Example of Active Fire/Corrected Reflectance Product Siberia (May 22, 2001) | **Example of 250 m Corrected Reflectance Product Hurricane Erin (September 11, 2001)** | **Example of Corrected Reflectance Product Dust Storm in Western Africa (May 8, 2001)**

Figure 1. This figure shows several early natural hazard images from the former MODIS Rapid Response Project—a forerunner to LANCE. All three images are corrected reflectance products showing an active fire over Siberia from May 22, 2001 [*left*]; a 250-m- (820-ft-) resolution image of Hurricane Erin obtained on September 11, 2001 [*center*]; and a dust storm over Western Africa on May 8, 2001 [right]. **Image credit:** Jacques Descloitres [MODIS Rapid Response Project]

By 2008 the combination of a growing demand for NRT data and the aging of the NRTPE servers spurred a NASA Headquarters-led effort to build a new, more robust system to process and distribute NRT products created from data in the EOSDIS collection. In July 2009 NASA's Earth Science Data and Information System (ESDIS) Project, which manages EOSDIS data, led the development of a new NRT system to serve data from MODIS as well as data from the Advanced Microwave Sounding Radiometer–EOS (AMSR-E) and Atmospheric Infrared Sounder (AIRS), both onboard NASA's Aqua satellite, and the Microwave Limb Sounder (MLS) and Ozone Monitoring Instrument (OMI), both onboard NASA's Aura satellite. This new system was formally established by NASA in September 2009 and named *LANCE*.

NASA's Global Imagery Browse Services (GIBS) and Worldview were game-changers in the way NRT imagery were distributed and used, and provided users with quick, easy, and stable access to daily NRT global imagery.

Developing the LANCE Architecture

LANCE is a virtual system that leverages EOSDIS capabilities originally intended to process standard data products designed for long-term Earth science research and applications. These capabilities were modified to deliver data products—generally within three hours from satellite instrument observation—to meet the needs of NRT user communities. All aspects—from geolocation data (e.g., attitude and ephemeris) to ground systems and, in some cases, inputs to the science algorithms—had to be modified to meet the LANCE three-hour latency requirement. **Figure 2** on page 7 shows an overview of the LANCE architecture.

LANCE consists of processing elements that are colocated with selected EOSDIS Distributed Active Archive Centers (DAACs) and Science Investigator-led Processing Systems (SIPS)—see **Figure 3** on page 7.

Development of GIBS and NASA Worldview

MODIS Rapid Response demonstrated not only the ability to provide NRT satellite instrument imagery, but also the value of quick and simple access to this imagery. The next step in LANCE development was to create a way for data users to easily download NRT imagery, interactively explore it, and then download the underlying

continued on page 8

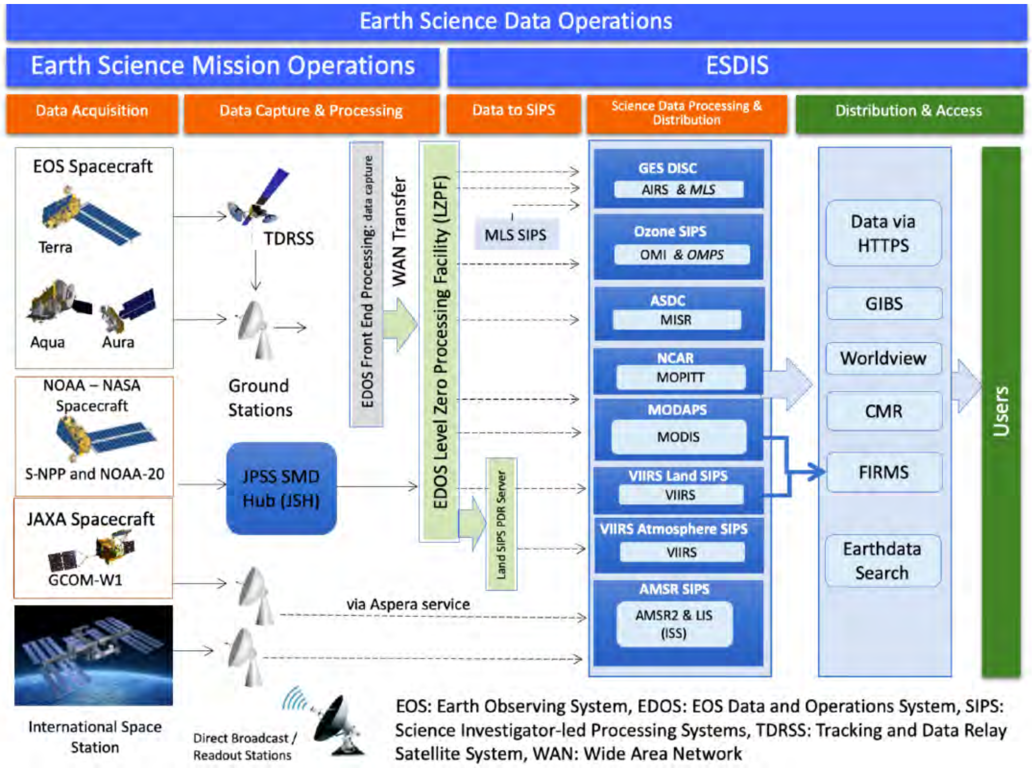
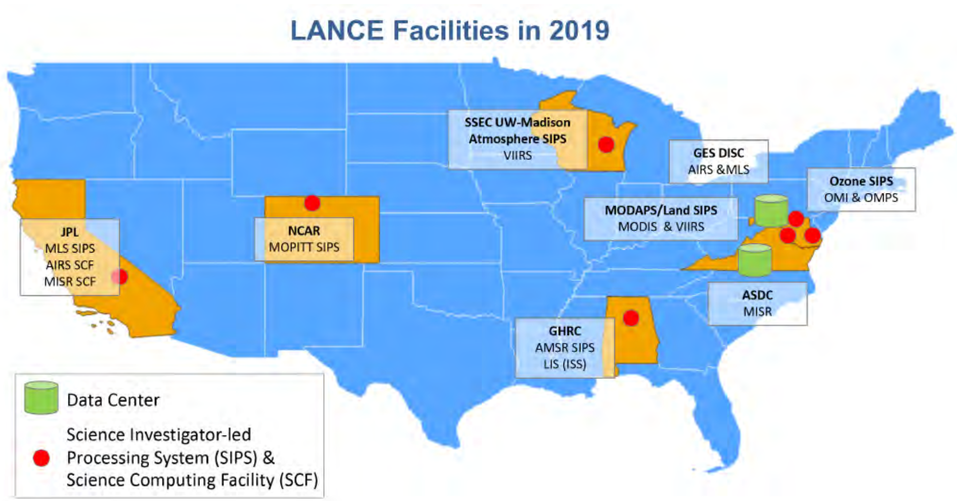


Figure 2. LANCE architecture showing a simplified overview of the dataflow from satellite to users. Acronyms used in the diagram that are not defined are either defined in the article text or easily found online. A farily comprehensive list of acronyms can be found at *https://earthdata.nasa.gov/learn/user-resources/acronym-list*. **Image credit**: ESDIS Project



The LANCE elements are located at the following facilities:

- **GSFC Earth Sciences Data and Information Services Center (GES DISC)** is providing AIRS with support from the AIRS Science Computing Facility (SCF) at JPL, and MLS data via the MLS SIPS at JPL;
- **Atmospheric Science Data Center (ASDC)** is providing MISR data with support from the MISR SCF at JPL;
- **AMSR Science Investigator-led Processing System (SIPS)** is providing AMSR2 and LIS data;
- **MODIS Adaptive Processing System (MODAPS) and Land SIPS** are providing MODIS and VIIRS Land data;
- **Ozone Science Investigator-led Processing System (SIPS)** is providing OMI and OMPS data;
- **MOPITT SIPS [National Center for Atmospheric Research (NCAR)]** is providing MOPITT data; and
- **Atmosphere SIPS [Space Science and Engineering Center (SSEC) University of Wisconsin]** is providing VIIRS Atmosphere data.

Figure 3. Location of LANCE elements in NASA's EOSDIS system. Acronyms used in the diagram and descriptions that are not defined are either defined in the article text or in the online acronym list referenced in Figure 2. **Image credit**: LANCE

data behind the imagery. These efforts culminated in the development of the LANCE-powered Global Imagery Browse Services (GIBS, *https://earthdata.nasa.gov/eosdis/science-system-description/eosdis-components/gibs*) and the NASA Worldview (*https://worldview.earthdata.nasa.gov*) interactive data visualization application in 2011.[7] GIBS and NASA Worldview were game-changers in the way NRT imagery were distributed and used, and provided users with quick, easy, and stable access to daily NRT global imagery.[8] **Figure 4** shows an example of an image generated using NASA Worldview.

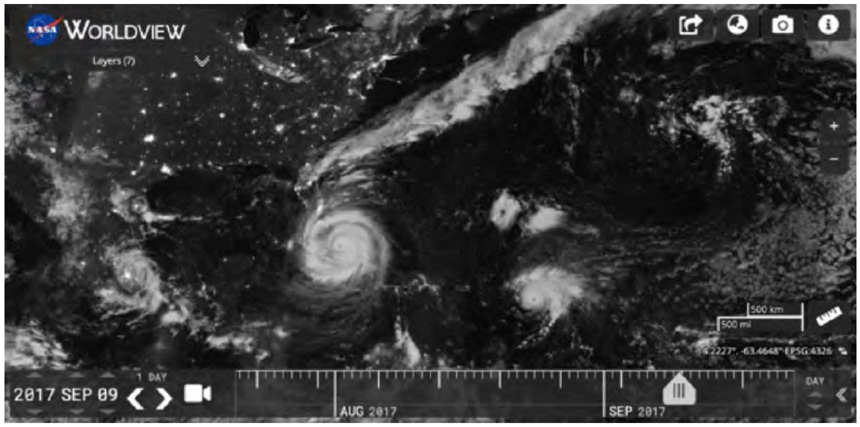


Figure 4. NASA Worldview screenshot of nighttime imagery from September 9, 2017, produced from Visible Infrared Imaging Radiometer Suite (VIIRS) data showing Hurricane Irma south of Florida. MODIS and VIIRS NRT Corrected Reflectance imagery are the most-viewed imagery in GIBS and NASA Worldview, followed by VIIRS nighttime imagery. **Image credit**: NASA Worldview

FIRMS Becomes Part of LANCE

As noted earlier, one impetus to produce NRT data from NASA EOS missions came from the need to help the USGS monitor and track wildfires. This application is still a key use of NRT data, and led to developing the Fire Information for Resource Management System (FIRMS). UMD developed FIRMS in 2007 with funding from NASA's Applied Sciences Program and the United Nations Food and Agriculture Organization (UNFAO). NASA began offering FIRMS NRT data in 2007 and the UNFAO began offering the data in 2010 through its Global Fire Information Management System (GFIMS). FIRMS was transitioned to LANCE in May 2010 and became formally operational in LANCE in May 2012.[9]

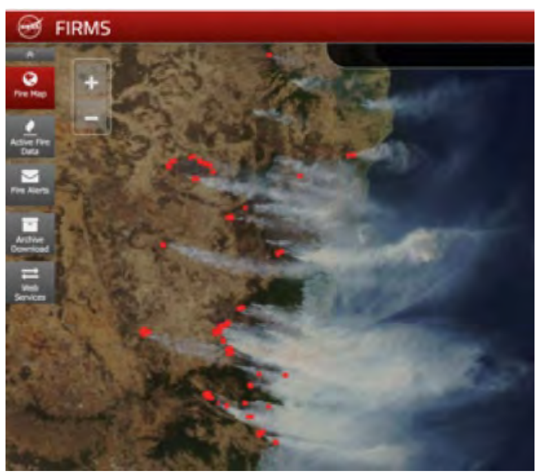


Figure 5. Each white dot on this FIRMS Fire Map represents the approximate location of an active fire in New South Wales, Australia, on November 13, 2019. The detected hotspots are overlaid on an image from VIIRS on a Suomi NPP Corrected Reflectance true-color image. **Image credit**: LANCE/FIRMS

FIRMS provides NRT thermal anomaly data (including an approximate location of a detected hotspot) from NASA's MODIS and Visible Infrared Imaging Radiometer Suite (VIIRS)[10] instruments. Global active fire detections can be viewed interactively using the FIRMS Fire Map application[11]—see the example in **Figure 5**—and FIRMS users

[7] The Rapid Response system was phased out in 2019 and has been replaced with Worldview Snapshots (*https://wvs.earthdata.nasa.gov*).

[8] To learn more about GIBS and Worldview, see "NASA's Worldview Places Nearly 20 Years of Daily Global MODIS Imagery at Your Fingertips" in the July–August 2018 issue of *The Earth Observer* [**Volume 30, Issue 4**, pp. 4-8—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/July-August%202018%20Color%20508.pdf#page=4*].

[9] To learn more about FIRMS, see "NASA FIRMS Helps Fight Wildland Fires in Near Real-Time" in the March–April 2017 issue of *The Earth Observer* [**Volume 27, Issue 2**, pp. 14-17—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Mar_Apr_2015_color_508.pdf#page=14*].

[10] VIIRS currently flies on the joint NASA/NOAA Suomi National Polar-orbiting Partnership (NPP) mission and on the NOAA-20 satellite, formerly known as the Joint Polar Satellite System–1 (JPSS-1). VIIRS will fly on JPSS-2 through -4.

[11] To learn more about the FIRMS Fire Application, see *https://firms.modaps.eosdis.nasa.gov/map/#z:3;c:0.0,0.0;d:2019-12-10..2019-12-11*.

can sign up to receive email alerts notifying them of potential fires detected in specific areas of interest. Through this free service, alerts can be received in NRT or as daily or weekly summaries. Every week approximately 240,000 FIRMS Fire Alerts (including daily alerts, rapid alerts, and weekly alerts) are sent to users in more than 160 countries.

Distribution of LANCE Data to End Users

In addition to distributing imagery through GIBS, LANCE products also are available through numerous additional EOSDIS services including: the Earthdata website (*https://earthdata.nasa.gov*); the Earthdata Search data discovery and exploration application (*https://search.earthdata.nasa.gov*); Earthdata Login, which enables data in the EOSDIS collection to be downloaded; the Common Metadata Repository (CMR), which is the foundation for EOSDIS data discovery; and the User Support Tool, which allows users of EOSDIS services to ask questions, report issues, or provide general feedback. Providing centralized access to these support services means users benefit from the specialization of duties. For example, the User Support Tool allows experts from LANCE elements across the U.S. to focus on providing quality support to end users, while the distributed LANCE SIPS focus on data quality and providing timely data. This modular approach enables new capabilities (e.g., data from a new instrument) to be added to LANCE with relative ease.

Every week approximately 240,000 FIRMS Fire Alerts (including daily alerts, rapid alerts, and weekly alerts) are sent to users in more than 160 countries.

The LANCE User Working Group (UWG)

While NASA's ESDIS Project manages LANCE, it is steered by a User Working Group (UWG)[12] responsible for providing guidance and recommendations concerning a broad range of topics related to the LANCE system, capabilities, and services. The LANCE UWG represents the broad needs of the LANCE applications user communities, while maintaining close ties with the various instrument science teams included in LANCE. UWG recommendations are made to the ESDIS Project to evaluate feasibility and implementation costs.

In December 2009, ESDIS held a workshop to better understand the needs of LANCE users and to nominate the first members of the LANCE UWG.[13] **Miguel Román** [Universities Space Research Association, formerly at GSFC—*Founder of Earth from Space Institute*], is the current LANCE UWG chair following on from **Christopher (Chris) Justice** [UMD—*Chair of the Department of Geographical Sciences*], who served as LANCE UWG chair for 10 years.

Adding Capabilities to LANCE

The addition of Advanced Microwave Scanning Radiometer 2 (AMSR2) data from the Japan Aerospace Exploration Agency's first Global Change Observation Mission–Water (GCOM-W1) satellite in March 2015 was the first non-EOS mission data added to LANCE. Currently, six unique AMSR2 data products are available through LANCE.

The Lightning Imaging Sensor (LIS) was installed on the International Space Station in February 2017, and LIS data became the first data from a space station-based instrument available through LANCE. LANCE LIS data are available within two minutes of observation and provide total lightning measurements between ±48° latitude, a geographic range that includes nearly all global lightning.

[12] For more information, visit *https://earthdata.nasa.gov/earth-observation-data/near real-time / about-lance#ed-lance-uwg*.

[13] To learn more, read "Land and Atmosphere Near Real-Time Capability for EOS (LANCE) Workshop Summary" in the March–April 2010 issue of *The Earth Observer* [**Volume 22, Issue 2**, pp. 18-20—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/Mar_Apr10.pdf#page=18*].

Along with new instrument data, new data products are constantly being added to the system. Recent additions include:

- VIIRS Nighttime Imagery product—made available in January 2017;
- OMPS Pyrocumulonimbus product (PyroCb)—made available in October 2018;
- MODIS Thermal Alert System (MODVOLC)—made available in 2018 to serve the volcano-monitoring community and distributed primarily through the University of Hawaii;
- MODIS Multi-Angle Implementation of Atmospheric Correction (MAIAC) model—made available in 2019 to support the air-quality and climate/atmospheric-modeling communities; and
- MODIS Global Near Real-Time Flood Product—expected to be available in spring 2020.

Today, LANCE provides 215 image and derived data products and distributes more than 16 terabytes of NRT data per week to data users worldwide.

Current LANCE Status

Today, LANCE provides 215 image and derived data products and distributes more than 16 terabytes (TB) of NRT data per week to data users worldwide—see **Table**. The demand for these products comes from applications users, operational agencies, and scientists who use these products to support NRT research and applications in weather prediction, natural-hazards and air quality monitoring, agriculture, disaster relief, and homeland security.

Table. Instruments currently providing NRT data and imagery through LANCE. Acronyms can be found in the article text or in the online acronym list referenced in the caption for Figure 2.

Instrument	Product Categories	Year Data Were Added to LANCE	Average Latency* (minutes)	Number of NRT Products	
				Data products	GIBS Imagery layers
AIRS	Radiances, temperature, moisture profiles, precipitation, dust, clouds, and trace gases	November 2009	75-140	9	50
AMSR2	Global total precipitation, global rainfall, total precipitable water, ocean wind speed, columnar cloud liquid water (over ocean), columnar water vapor (over ocean), snow water equivalent, sea ice concentration, brightness temperature, soil moisture	March 2015	75-165	6	20
LIS on ISS	Lightning, atmospheric electricity, weather events	March 2018	2	2	2
MISR	Cloud motion vectors (winds), radiances	June 2016	90-120	4	18
MLS	Ozone, temperature, carbon monoxide (CO), water vapor, nitric acid, nitrous oxide (N_2O), sulfur dioxide (SO_2)	November 2009	75-140	7	14
MODIS	Radiances, cloud aerosols, water vapor, fire, snow cover, sea ice, land surface reflectance, ephemeris/attitude	November 2009	60-125	75	92

*Latencies exclude daily Land Surface Reflectance and Level-3 products.

table continued on next page

Table. Instruments currently providing NRT data and imagery through LANCE (*continued*).

Instrument	Product Categories	Year Data Were Added to LANCE	Average Latency* (minutes)	Number of NRT Products	
				Data products	GIBS Imagery layers
MOPITT	Total column CO retrieved from thermal infrared radiances	October 2017	180	1	1
OMI	Ozone, SO_2, aerosols, cloud top pressure	November 2009	100-165	5	9
OMPS	Total column ozone and aerosol index, SO_2, ozone profile	*Suomi NPP*: December 2017	180	4	9
VIIRS	375-m (1230-ft) active fire, corrected reflectance and nighttime imagery, land surface reflectance, land surface temperature, snow cover, sea ice, ice surface temperature, cloud aerosols, cloud mask	*Suomi NPP*: October 2017 *NOAA-20*: August 2019	180	31	10

*Latencies exclude daily Land Surface Reflectance and Level-3 products.

LANCE Moves into its Second Decade

Looking to the future, the ESDIS Project plans to further enhance LANCE to produce and deliver NRT data from NASA and other partner agencies. In addition, new NRT datasets from planned missions where large user communities would benefit from their delivery will be explored. In doing this, NASA will continue to increase the societal value of its investment in Earth observations.

From the earliest investigations into the feasibility of collecting NRT data from Terra, to the more than 200 NRT products available today through LANCE, the ability to deliver NRT data from Earth observing satellites has come a long way—and is a tremendous success story. The availability of NRT data further increases the use of these data and broadens the user communities who now use them. As LANCE enters its second decade, NRT Earth-observing data and derived products are now integral tools being used globally to protect lives and property. NASA successfully leverages existing systems to provide NRT data at little extra cost to the standard processing, search, and delivery systems. The systems, strategies, and services developed by LANCE scientists and engineers not only complement standard data products in the EOSDIS collection, but further enhance the value of these data.

From early investigations into whether NRT data were even possible to the more than 200 NRT products currently available through LANCE, the ability to deliver NRT data from Earth observing satellites is a tremendous success story.

Acknowledgement

The authors would like to recognize the contributions of the Worldview/GIBS Team led by **Ryan Boller** [GSFC] and **Matthew Cechini** and **Minnie Wong** [both at GSFC/SSAI] for their contributions to this article. ■

Earth to Sky Partnership Helps Connect the Wonders of NASA Science with the Power of Place

Anita Davis, NASA's Goddard Space Flight Center/Science Systems and Applications, Inc., anita.l.davis@nasa.gov

The work of the Earth to Sky partnership is accomplished through professional development that connects scientists with informal educators in a collegial learning environment, and through nurturing and sustaining the resulting community of practice.

About Earth to Sky

Earth to Sky (ETS; *https://earthtosky.org*) is an ongoing and expanding partnership between NASA, the U.S. National Park Service (NPS), the U.S. Fish and Wildlife Service, and similar organizations. Its activities began in 2004 via an internal NASA grant. ETS enables and encourages informal educators (e.g., interpreters and environmental educators) to access and use relevant NASA science, data, and educational and outreach products in their work. ETS also coaches science presenters in adopting proven-effective science communication techniques.

Informal educators who connect real-world experience on public lands with NASA's cutting-edge science and exploration help the public realize deep meaning and relevance for science and for conserved sites (e.g., sites under NPS management). This connection between science and place-based experience creates powerful and long-lasting impressions that motivate further learning. The ultimate goal is to increase climate science literacy and environmental stewardship among the public, educators, and students—see **Photo 1**.

Photo 1. National Park Service (NPS) ranger interpreting forest ecology with families and children. **Photo credit:** NPS

ETS Training Courses

The first ETS training course took place in 2004, not long after the ETS partnership was established. At that time, **Anita Davis** [NASA's Goddard Space Flight Center (GSFC)/Science Systems and Applications, Inc. (SSAI)] was leading the Landsat Education and Public Outreach team. She collaborated with **Ruth Paglierani** [University of California, Berkeley, Center for Science Education] and staff from the NPS Training Division to develop the first course. Two classes were run simultaneously: one at NASA's Ames Research Center, the other at NPS's Mather Training Center in Harpers Ferry, WV, which included a day trip to GSFC. The classes were briefly joined via live video conferencing—a fairly new technology at the time. Content for both classes was drawn from the breadth of NASA's science divisions. Each participant created a plan for using course content in their work. Participants' products ranged from in-person ranger talks to brochures, formal education programs, and traveling exhibits. Some of these products continue to be updated and are in use today. Several participants from this first course remain involved in ETS as coaches and presenters for courses and conference presentations. Since 2007 course content has focused primarily on climate change science and communication. The partnership remains strong and has expanded to include other agencies and nonprofit organizations. Today, Davis and Paglierani remain active members of the ETS leadership team—shown in **Photo 2**.

Photo 2 The Earth to Sky Leadership Team joined to run the first ETS Academy. [*Left to right*]: **Brad Davey** [Tech for Learning—*ETS Evaluator*] **Geneviève de Messières** [GSFC/SSAI—*ETS Lead*]; **John Morris** [GSFC/SSAI—*ETS Alaska*]; **Ruth Paglierani** [GSFC/SSAI—*ETS Consultant*); **Jenna Giddens** [ETS, *retired*]; **Matt Holly** [NPS Climate Change Response Program]; **Anita Davis** [GSFC/SSAI—*ETS Co-lead*]; and (not pictured) **Larry Perez**. [NPS Climate Change Response Program]. **Photo credit**: Geneviève de Messières

Professional Development Methodology

All ETS courses employ a modified "Authentic Task Approach©" developed by Learning Innovations, a division of WestED, in which content is consistently applied to real-world tasks in participants' work environments. Each participant develops an action plan for using course content as they work to educate the public, teachers, and students.

ETS presenters and participants appreciate the collegial learning environment of the courses in which everyone involved is considered equally essential to the success of the course. Prior to each course, ETS coaches (selected ETS alumni) are paired with scientists to ensure that presentations are of an appropriate scope and level for the course participants. Scientists often remark on how helpful these coaching sessions are and share their plans to alter their presentation techniques for other audiences, as well. During the course, each coach also mentors an assigned small group of four-to-five participants and provides an example of how they have used ETS content in their respective activities.

Robust evaluation has significantly contributed to the partnership's success. Formative evaluation helped improve early versions of the courses, and longitudinal analysis demonstrated the effectiveness of the ETS approach.

Robust evaluation has significantly contributed to the partnership's success. Formative evaluation helped improve early versions of the courses, and longitudinal analysis demonstrated the effectiveness of the ETS approach. Evaluations consistently indicate that the majority of participants put their plans into action at their home setting: e.g., parks, refuges, hatcheries, museums. Products include exhibits, public programs, brochures, and educator training. Some examples of participants' work are featured in the online ETS Showcase at *https://www.earthtosky.org/showcase.html*.

One hallmark of the ETS training model is purposeful, ongoing engagement with participants after courses are held. This encourages continued learning and the building of a community of practice. The ETS listserv, periodic webinars, and conference presentations serve the existing loosely knit community, which currently numbers over 800 science communication practitioners distributed across the U.S. and the Northwest Territories of Canada.

The Evolution of a Regional Approach

The ETS Leadership Team desires to strengthen the existing ETS community and expand and deepen its impact. However, supporting the ETS dispersed national community has proved challenging—because it is difficult to keep up with so many people with so many varied needs and interests. Concerns about travel costs and the carbon footprint for long-distance travel, combined with the knowledge that course participants are most interested in locally relevant content, made a regional approach the logical next step.

In 2015 ETS began to run shorter, regionally focused courses on climate science and communication. The courses were successful, and demand quickly outpaced the number of courses that ETS could provide. Experience with ETS's first regional community (in Alaska) indicated the viability of developing ETS Regional Communities of Practice as a program-wide approach. It also pointed to the need for training small teams of leaders for each region, who could share the responsibilities of running a course and who would sustain and nurture their community.

With these modifications, the seed for the ETS Academy (hereinafter, *Academy*)—a week-long course designed to build a network of ETS Regional Leaders—was sown.

The ETS Academy is aimed at experienced informal educators and climate communication leaders who have a strong commitment to the ETS partnership and to furthering climate literacy within their respective regions.

About the Earth to Sky Academy

The Academy is aimed at experienced informal educators and climate communication leaders who have a strong commitment to the ETS partnership and to furthering climate literacy within their respective regions. Participants attend in teams of three to five individuals, so the regional responsibilities can be shared among individuals and the organizations for which they work.

Each team submits an application that outlines their team's expertise in climate science communication and professional development, describes the geographic extent of the region they plan to serve, and characterizes their intended audience. Teams are selected based upon an assessment of their ability and commitment to:

- catalyze, nurture, and sustain their regional community of practice of climate science communicators;
- develop and conduct effective ETS-style professional development events in their region; and
- participate in the ETS Regional Leaders Network to further the mission of ETS.

A major goal for each ETS regional course is to strengthen or launch a regional community of practice. The ETS Leadership Team recognized the need to develop an *ETS Course Guidebook* (hereinafter, *Guidebook*), both to maintain fidelity to the successful ETS methodology and to provide support for the Regional Leaders. Drawing from 15 years of experience and extensive evaluation of the ETS model, the Guidebook codifies the ETS methodology. It includes a detailed three-day regional course agenda; lesson plans for course sessions on community building, climate science, and communication techniques; a detailed course preparation timeline; a guide to roles and responsibilities; templates for course announcements; and other supporting documents.

During the Academy participants are provided with the Guidebook. They receive instruction in effective adult education methodology and the ETS professional development model, tips on building and nurturing communities of practice, updates on climate science, an introduction to NASA's climate science and outreach resources, instruction on effective climate communication techniques, and examples of effective climate-science communication.

Throughout the weeklong Academy, the teams engage with one another and NASA staff and begin drafting a plan to develop a regional course in climate science and communication using content and resources drawn from NASA, NPS, and their regional partners.

Throughout the weeklong Academy, the teams engage with one another and NASA staff and begin drafting a plan to develop a regional course in climate science and communication using content and resources drawn from NASA, NPS, and their regional partners.

Academy graduates attend follow-up webinars on a regular basis to receive guidance, support, and continuing education as each team develops and runs its own course. ETS provides website support for each region's course information and archives, assistance in locating potential NASA presenters and NASA resources to share with their respective communities, and ongoing mentoring.

Summary of the First Earth to Sky Academy

The first Academy took place at GSFC October 21-25, 2019. Four teams of informal educators were selected to attend: Southeast (SE) Alaska, Idaho, South Central U.S. (OK, NM LA, TX), and the Upper Delaware River region of New York and Pennsylvania—see **Photo 3**. The team members work at a variety of federal, state, and local government agencies and nongovernmental organizations including the NPS, U.S. Forest Service, National Oceanographic and Atmospheric Administration (NOAA), University of Oklahoma, NASA Oklahoma Space Grant Consortium, the Chickasaw Nation, University of Idaho, Lake City High School (Coeur d'Alene, ID), the Boise WaterShed Environmental Education Center, Idaho Department of Parks and Recreation, Georgetown College (KY), the Himalayan Institute (Honesdale, PA), and the Sullivan County Office of Sustainable Energy (NY).

Photo 3. The participants in the inaugural ETS Academy class held at GSFC October 21-25, 2019. **Photo credit**: Geneviève de Messières

Each team plans to serve a particular audience within their respective geographic regions. Team SE Alaska will focus on informal educators and interpreters that have contact with visitors; Team Idaho will foster collaborations between interpreters and formal educators to create site-based environmental education experiences; Team South Central U.S. will work with tribal environmental staff and tribal educators; and Team Upper Delaware River will focus on community policymakers and influencers along both sides of the Delaware River.

GSFC scientists and outreach staff presented interesting and useful information during the 2019 Academy session, as described below.

Peter Griffith [GSFC/SSAI—*Director of NASA's Carbon Cycle & Ecosystems Office*], a long-standing supporter of ETS, delivered a plenary climate science presentation which linked the local regional carbon cycle to global warming and rapid environmental changes in the Arctic.

Doug Morton [GSFC—*Chief of the Biospheric Sciences Laboratory*] joined with **Christa Peters-Lidard** [GSFC—*Deputy Director for Hydrosphere, Biosphere, and Geophysics* for the *Earth Sciences Division*] in a special colloquium on the role of fire and the hydrological cycle in Earth's climate system. The colloquium included discussion on effective climate science communication, followed by a social hour during which GSFC scientists and Academy participants had the opportunity to share their ideas and expertise.

Christopher Shuman [GSFC/University of Maryland, Baltimore County (UMBC)—*Research Scientist* in the *Cryospheric Sciences Laboratory*] shared specific resources on his Alaska glacier research with the team from SE Alaska in a productive and ongoing collaboration.

Academy participants visited the Goddard TV studio where **Jefferson Beck** [GSFC/Universities Space Research Association—*Earth Science Video Producer*] demonstrated a variety of resources available to informal educators from the GSFC Office of Communications.

Special presentations at GSFC's Hyperwall—a multiscreen, high-definition videowall—featured **Lori Perkins** [GSFC—*Computer Engineer*], who showed a wealth of visual resources available to informal educators from the GSFC Scientific Visualization Studio—see **Photo 4**, and **Claire Parkinson** [GSFC—*Climate Change Senior Scientist*], who showed visualizations and information about polar ice research—see **Photo 5.**

Photo 4. Lori Perkins describes Scientific Visualization Studio resources. **Photo credit**: Geneviève de Messières

Photo 5. Claire Parkinson presents information on polar ice research during her Hyperwall presentation. **Photo credit**: Geneviève de Messières

Several GSFC outreach specialists provided information on various NASA Earth science missions and engaged participants with hands-on activities, including the GLOBE Observer citizen science app.[1] Presenters included **Lauren Antt** [GSFC], **Eric Brown de Colstoun** [GSFC–*Physical Scientist in the Biospheric Sciences Laboratory*], **Brian Campbell** [Wallops Flight Facility/Global Science & Technology, Inc.—*NASA Earth Science Education and Communication Specialist*], **Ginger Butcher** [GSFC/SSAI—*Outreach Lead, Landsat*], **Kristen Weaver** [GSFC/SSAI—*Deputy Coordinator for GLOBE Observer*], **Heather Mortimer** [GSFC/SSAI—*Graphic Designer/Technical Writer for the GLOBE Program*], **Valerie Casasanto** [GSFC/UMBC—*Outreach Lead, ICESat-2*], and **Dorian Janney** [GSFC/ADNET—*GPM Outreach Specialist*].

Trena Ferrell [GSFC—*Outreach Lead for the Earth Sciences Division*] led the group on a tour of the GSFC test facility, which included an update from **Julie McEnery** [GSFC—*Senior Scientist, High Energy Astrophysics*] on the Wide Field Infrared Survey Telescope (WFIRST) mission, a NASA observatory designed to unravel the secrets of dark energy and dark matter, search for and image exoplanets, and explore many topics in infrared astrophysics.

Fifteen years after its creation, the ETS partnership is stronger than ever as development of a national network of regional communities gets underway.

Each Academy team formulated and then reported on their draft plan for conducting a regional ETS climate science and communication workshop and stated their commitment to support their communities of practice—e.g., see **Photo 6**. Two teams expect to run their first courses in summer of 2020; the others will run theirs in 2021.

Photo 6. Academy participant **Emma Johnson** reports on Team SE Alaska's plan for developing an ETS regional community of practice centered on Wrangell–St. Elias and Glacier Bay National Parks. **Photo credit**: Geneviève de Messières

Conclusion

Fifteen years after its creation, the ETS partnership is stronger than ever as development of a national network of regional communities gets underway. The four regional teams from the first ETS Academy will be launching their regional communities of practice by mid-2021. Each will differ in the scope and size of its community, according to the specialized needs of the specific regions. With interest already building for additional regional communities, the ETS Leadership Team is planning for the second Academy to be run in early 2021. ETS will provide distance learning and community-building support for Academy graduates in coming months and years and continue supporting the national ETS community of practice. ■

[1] For more information about GLOBE Observer, read "Globe Observer: Citizen Science in Support of Earth Science" in the November–December 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 6**, pp. 15-21—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Nov_Dec_2017_color_508.pdf#page=15*]. To learn more about GLOBE Observer and download the Globe Observer app, visit *https://observer.globe.gov/en*.

NASA Lights the Way at the 2019 AGU Fall Meeting

Heather Hanson, NASA's Goddard Space Flight Center/Global Science & Technology, Inc., heather.h.hanson@nasa.gov
Tassia Owen, NASA's Goddard Space Flight Center/Global Science & Technology, Inc., tassia.owen@nasa.gov

Introduction

As the American Geophysical Union (AGU) marked its Centennial in 2019, the AGU's Fall Meeting returned to San Francisco, CA, December 9-13, 2019, after a two-year hiatus due to renovations at the Moscone Center, the meeting's traditional home.

As they have done for more than a dozen years, NASA's Science Support Office (SSO)[1] staff organized and supported the NASA exhibit at the AGU Fall Meeting. With help from the NASA outreach community the 50- x 50-ft (15- x 15-m) exhibit space showcased the depth and breadth of NASA's science activities.

The 2019 exhibit theme was "NASA Lights the Way." The theme centered on the release of NASA's new 200-page *Earth at Night* book. The exhibit featured NASA's Hyperwall,[2] a "NASA Lights the Way" LED back-lit display, and three interactive areas that represented science activities from the Science Mission Directorate's (SMD) four disciplines: Earth Science, Planetary Science, Heliophysics, and Astrophysics.

Amidst the hustle and bustle of the AGU meeting, NASA's Terra mission was recognized in several different capacities to commemorate its twentieth year in orbit, including a Hyperwall presentation and representation at the NASA exhibit, two oral sessions, as well as an evening reception—see *NASA's Terra Mission Celebrates 20 Years in Orbit* on page 22.

This article contains a number of photographs from the AGU Fall Meeting. Many more photos from NASA's exhibit activities at the meeting can be viewed at *https://www.flickr.com/photos/eospso/albums/72157712263818707/page3*.

The day before the start of the AGU Fall Meeting, on December 8, the SSO supported the 2019 Annual SMD Communications Meeting in San Francisco. The meeting allowed NASA employees and contractors who contribute to the agency's communications activities at many different NASA centers to convene, all in one place, to shape outreach communications strategies and guide the workflow for the coming year—see *Annual SMD Communications Meeting*, below.

[1] The SSO, formerly the Science Communications Support Office, is the primary point of contact for NASA's Science Mission Directorate (SMD) and Earth Science Division (ESD) for science exhibit outreach and product development.
[2] NASA's Hyperwall is a video wall capable of displaying multiple high-definition data visualizations and/or images simultaneously across an arrangement of screens. To view the full library of Hyperwall visualizations and stories, visit *https://svs.gsfc.nasa.gov/hw*.

Annual SMD Communications Meeting

The 2019 Annual SMD Communications Meeting was held at the San Francisco Marriott Union Station, on Sunday, December 8, 2019. More than 180 NASA employees and contractors attended the daylong event. This meeting is an opportunity for those involved in NASA's communications activities, who have gathered in San Francisco for the AGU Fall Meeting, to meet face-to-face and shape outreach communications strategies and guide workflow for the coming year.

Kristen Erickson [NASA HQ—*Director of Science Engagement and Partnerships*] provided opening remarks and a welcome message, and introduced **Steve Clarke** [NASA HQ—*SMD Deputy Associate Administrator for Exploration*] who shared his vision of the "state of SMD" and the agency's communication strategies. Next, four SMD division heads—**Sandra Cauffman** [NASA HQ—*Acting Director of the Earth Science Division*], **Nicola Fox** [NASA HQ—*Director of the Heliophysics Science Division*], **Lori Glaze** [NASA HQ—*Director of the Planetary Science Division*], and **Paul Hertz** [NASA HQ—*Director of the Astrophysics Science Division*]—spoke about the state of their respective SMD programs. In addition, **Mamta Patel Nagaraja** [NASA HQ—*Deputy Director for Strategic SMD Content*] and **Greg Hautaluoma** [NASA HQ—*Senior Communications Official for SMD*] spoke about the agency's science content development and implementation strategies and communication updates. In the afternoon, there were breakout sessions for Earth Science, Planetary Science, and Heliophysics activities, where participants discussed story ideas.

NASA Exhibit Details

The NASA exhibit was extremely popular this year, owing to nearly 100 dynamic Hyperwall presentations (15 minutes in length) and Flash Talks (7 minutes in length), the *Earth at Night* book release and designated signing times, distribution of the 2020 NASA Science calendar,[3] 30 tabletop exhibits, hands-on demonstrations, and a wide range of printed materials (e.g., mission brochures, story booklets, fact sheets, and lithographs).

The focal point of the exhibit experience continues to be the nine-screen Hyperwall. **Sandra Cauffman** [NASA Headquarters (HQ)—*Acting Director of the Earth Science Division*] provided opening remarks in front of the Hyperwall during the Centennial Opening Night Celebration and Ice Breaker held in the exhibit hall, Monday, December 9—see **Photo 1**. She announced the release of NASA's *Earth at Night* book, and shared important updates about NASA's SMD and Earth Science Program. **Alex Young** [NASA's Goddard Space Flight Center (GSFC)—*Associate Director of Science in the Heliophysics Science Division*], **Eleanor (Kellie) Stokes** [GSFC/University of Maryland, College Park], **Paula Bontempi** [NASA HQ—*Acting Deputy Director of the Earth Science Division*], **Kelsey Young** [GSFC], and **Nicola Fox** [NASA HQ—*Director of the Heliophysics Science Division*] also gave Hyperwall talks on opening night, covering a variety of topics including heliophysics science from the Moon, Earth at night, Earth's living ocean, the Artemis Program, and studying everything under the Sun, respectively.

Photo 1. Sandra Cauffman provided introductory remarks in front of the Hyperwall on opening night. **Photo credit:** NASA

Throughout the remainder of the week, visitors were immersed in themes that showed how NASA expands the frontiers of science through investigations of Earth science, heliophysics, planetary science, and astrophysics—see **Photos 2-5**. To view the daily events agenda, visit *https://eospso.gsfc.nasa.gov/sites/default/files/publications/AGU%20Events%20Program%202019_508.pdf.*

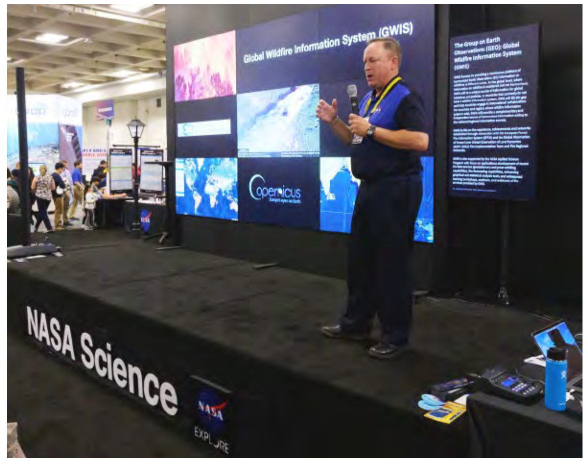


Photo 2. NASA's Hyperwall was the focal point of the exhibit. **Photo credit:** NASA

Photo 3. Attendees talked with NASA staff about NASA Earth Science data availability. The large antenna reflector (model size) for NASA's Soil Moisture Active Passive (SMAP) mission can be seen in the background. The antenna is SMAP's most prominent feature. **Photo credit:** NASA

Photo 4. The NASA exhibit offered a variety of booklets, fact sheets, brochures, and other informational handouts. **Photo credit:** NASA

[3] To view the 2020 NASA Science calendar online, visit *https://eospso.gsfc.nasa.gov/sites/default/files/publications/2020%20NASA%20Science%20Calendar%20508%20final.pdf.* The calendar is also available in Spanish at *https://eospso.gsfc.nasa.gov/sites/default/files/publications/2020%20NASA%20Science%20Calendar%20Spanish%20508%20final%20reduced%20size.pdf.*

Photo 5. Attendees visiting the "NASA's Eyes" table (*https://eyes.nasa.gov*) navigated the free software program to explore Earth, the solar system, the universe, and the spacecraft exploring them. **Photo credit:** NASA

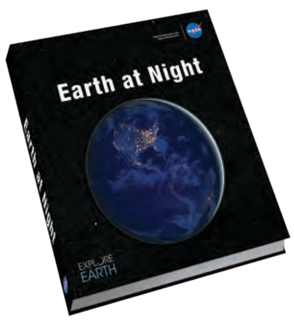
During two special lunchtime sessions at the NASA exhibit on December 10-11, **Thomas Zurbuchen** [NASA HQ—*Associate Administrator of SMD*], **Sandra Cauffman**, and **Paula Bontempi** joined representatives from AGU to introduce the winners of the NASA-funded *2019 AGU Data Visualization and Storytelling Competition*—a contest open to undergraduate and graduate students that focuses on innovation and creativity in presenting data to a larger audience in new, more easily accessible ways—see **Photos 6-7**. Having now completed its fourth year, the competition has been renamed the *AGU Michael Freilich Student Visualization Competition Program*, after past NASA Earth Science Director, **Michael Freilich**, who established the contest in partnership with the AGU. Freilich retired from NASA in February 2019.

Photo 6. Thomas Zurbuchen [*far left*] stands with AGU representatives and winners of the *2019 AGU Data Visualization and Storytelling Competition*. A sign renaming the competition to the *AGU Michael Freilich Student Visualization Competition Program* can be seen next to Zurbuchen [*left*]. **Photo credit:** NASA

Photo 7. Sandra Cauffman [*second from right*] and **Paula Bontempi** [*far left*] stand with representatives from AGU and winners of the *2019 AGU Data Visualization and Storytelling Competition*. **Photo credit:** NASA

NASA's New *Earth at Night* eBook

Even enshrouded in darkness, our planet has dazzling stories to tell! NASA has produced a new 200-page eBook that shows how humans and natural phenomena light up the darkness, and how and why scientists have observed Earth's nightlights for more than four decades, using both their own eyes and orbiting instruments.



Many of the images and captions used in the book originally appeared on NASA's *Earth Observatory* website (*https://earthobservatory.nasa.gov*). The book is divided into two main sections: "Nature's Light Shows" and "Human Light Sources." These sections feature images of natural and anthropogenic light sources, respectively. They illustrate how scientists use nightlight data to study our changing planet and how decision makers, in turn, can use the knowledge gained for public benefit. Some of these applications include forecasting urban energy use and carbon emissions, eradicating energy poverty and fostering sustainable energy development, providing immediate information when disasters strike, and monitoring the effects of conflict and population displacement.

The book is available online as a free eBook at *https://www.nasa.gov/connect/ebooks/earthatnight_detail.html*.

Measuring 10 x 11 inches, 1200 copies of NASA's new 200-page *Earth at Night* book were distributed to exhibit attendees. **Thomas Zurbuchen** signed the first 50 copies during the opening reception—see **Photos 8-9**.

James Green [NASA HQ—*Chief Scientist*], **Sandra Cauffman**, **Paula Bontempi**, and **Jack Kaye** [NASA HQ—*Associate Director for Research of the Earth Science Division*] signed an additional 1150 copies during designated times throughout the week—see **Photos 10-11**. For more information about the eBook version of the book, see *NASA's New* Earth at Night *eBook* on page 20.

Photo 8. Thomas Zurbuchen signed 50 copies of NASA's *Earth at Night* book during the opening reception at the AGU Fall Meeting. **Photo credit:** NASA

Photo 9. The "NASA Lights the Way" display was backlit by LEDs and served as a backdrop for the *Earth at Night* book signing. **Photo credit:** NASA

Photo 10. [*Foreground*] **James Green** and [*background*] **Jack Kaye** signed copies of the *Earth at Night* book. **Photo credit:** NASA

Photo 11. [*Seated left to right*] **Paula Bontempi**, **Sandra Cauffman**, and **Jack Kaye** signed copies of the *Earth at Night* book, while [*standing*] **Amy Treat** [NASA HQ] assists with distribution of the books. **Photo credit:** NASA

On December 12, NASA's Public Affairs Office held a 45-minute "Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx)" press event at the Hyperwall—see **Photos 12-13**.

Photo 12. OSIRIS-REx team members who participated in the NASA press event at the Hyperwall on December 12, 2019. **Photo credit:** NASA

Photo 13. [*Left to right*] **Lori Glaze** [NASA HQ—*Director of the Planetary Science Division*] talks with **Grey Hautaluoma** [NASA HQ—*Senior Communications Official for SMD*] about the OSIRIS-REx mission. **Photo credit:** NASA

After a year scoping out asteroid Bennu's boulder-scattered surface, the team leading NASA's first asteroid sample-return mission has officially selected a sample collection site. The OSIRIS-REx mission team concluded that a site designated *Nightingale*—located in a crater high in Bennu's northern hemisphere—is the best spot for the OSIRIS-REx spacecraft to snag its sample.

NASA's Terra Mission Celebrates 20 Years in Orbit

Terra, the flagship Earth Observing System (EOS) satellite, was launched December 18, 1999, from Vandenberg Air Force Base, CA. Designed and built in the 1980s and '90s, NASA and Lockheed Martin engineers set out to build a satellite that could take simultaneous measurements of Earth's atmosphere, land, and water. Its mission: *To understand how Earth is changing and to identify the consequences for life on Earth*.

Terra has chronicled these changes for 20 years, and continues to do so. Having well exceeded its expected design lifetime of six years, Terra is the longest continuously operating satellite to capture simultaneous measurements of Earth from five different sensors. Many of the climate data records produced by Terra's instruments are the longest ever produced by a single satellite mission. Terra's sensors are the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), Clouds and the Earth's Radiant Energy System (CERES), Multi-angle Imaging SpectroRadiometer (MISR), Moderate Resolution Imaging Spectroradiometer (MODIS), and Measurement of Pollution in the Troposphere (MOPITT).

The Terra mission celebrated its functional milestone at the AGU Fall Meeting with two oral sessions, a Hyperwall presentation, and representation within the NASA exhibit, as well as an evening reception.

Kurtis Thome [NASA's Goddard Space Flight Center (GSFC)—*Terra Project Scientist*], **Marcus Dejmek** [Canadian Space Agency], **Si-Chee Tsay** [GSFC—*Terra Deputy Project Scientist*], and **Robert Wolfe** [GSFC—*Terra Deputy Project Scientist for Data*] convened the oral session titled "Terra—20 Years as the Earth Observing System Flagship Observatory." The session included presentations about the contributions of each of Terra's instruments to scientific research over the past 20 years and the revolution they brought to how we monitor Earth's systems. Presentations showed how Terra data have contributed to quantifying Earth's greenness and the applications of this information to assessing how landcover has changed over the past two decades. Other details demonstrated Terra's contributions to the changes in infrared monitoring of active volcanoes, using the Urgent Request Protocol (*http://ivis.eps.pitt.edu/Project1.html*) to access MODIS and ASTER data. To read about these and other contributions made by Terra to science and society, visit *https://terra.nasa.gov/news/twenty-years-of-terra-in-our-lives*.

Jeanne Behnke [*Deputy Project Manager of Operations for the Earth Observing System Data and Information System (EOSDIS)*], **Dan Ziskin** [National Center for Atmospheric Research], **Amanda Leon** [University of Colorado, National Snow and Ice Data Center (NSIDC)], and **Chris Doescher** [U.S. Geological Survey, Earth Resources Observation and Science (EROS) Center] convened the oral session titled "Terra@20: Data System Evolution to Advance Climate Research." Speakers presented information on a variety of Terra results that have shaped how climate research has evolved, and showcased improvements in data access, production, and continuity. Presenters included experts on each of Terra's instruments, who described the evolution of data products from ASTER, CERES, MODIS, MISR, and MOPITT. They also described improvements to specific datasets, such as MODIS's sea surface temperature data, which now includes algorithm improvements for cloud screening and atmospheric corrections for dust. Additionally, presenters discussed improvements to supporting real-time data access—with significant advances in application areas and scientific collaboration.

At the NASA exhibit, **Kurtis Thome** gave a Hyperwall presentation to an eager audience—see **Photo 14**. He spoke about Terra's major scientific contributions over the past 20 years, focusing on how Terra's sensors work in concert for different applications and research.

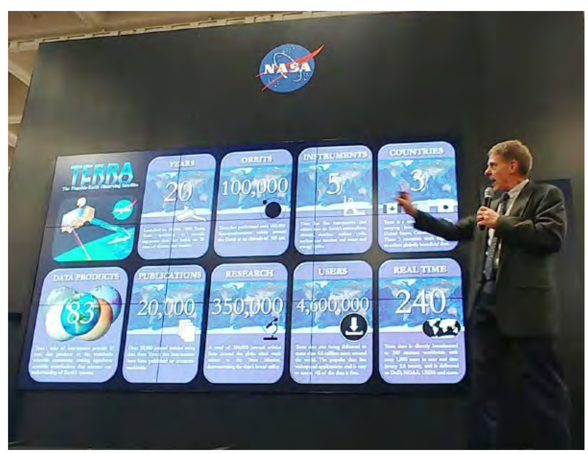


Photo 14. Kurtis Thome spoke in front of the Hyperwall about Terra's 20 years in orbit. **Photo credit:** NASA

Located in the hands-on tabletop area at the exhibit, **Tassia Owen** [GSFC/Global Science & Technology, Inc.] conversed with conference participants and answered questions about the Terra mission and its data. Two new videos about Terra's contributions (*https://svs.gsfc.nasa.gov/13493*) were showcased on a plasma screen. AGU attendees were also invited to

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Summary of the 2019 Precipitation Measurement Mission Science Team Meeting

Andrea Portier, NASA's Goddard Space Flight Center/Science Systems and Applications, Inc., andrea.m.portier@nasa.gov
Dalia Kirschbaum, NASA's Goddard Space Flight Center, dalia.b.kirschbaum@nasa.gov

Introduction

The 2019 annual Precipitation Measurement Missions (PMM) Science Team Meeting (STM) took place in Indianapolis, IN, November 4-8, 2019. The PMM program supports scientific research and applications, algorithm development, and ground-based validation activities for the Tropical Rainfall Measuring Mission (TRMM)[1] and Global Precipitation Measurement (GPM) mission—including the GPM Core Observatory.[2] There were 132 attendees from NASA, the Japan Aerospace Exploration Agency (JAXA), the U.S. National Oceanic and Atmospheric Administration (NOAA), universities, and other partner agencies, including 19 attendees from 6 countries outside the U.S.

There were 55 oral presentations across 12 sessions, as well as 142 posters presented during two poster sessions that spanned two days. The topics covered in these presentations and posters ranged from algorithm development to the use of datasets for scientific research and societal applications. Mission status and ground-validation (GV) efforts were also heavily covered during the meeting. In addition to presentations and poster topics, there were 15 working group meetings held throughout the week, covering specialty topics including group meetings for members of the Joint PMM ST[3] and Committee on Earth Observation Satellites (CEOS) groups.[4] Highlights from the meeting are summarized in this report. For more information about GPM data products, science team activities, and future updates, visit *https://pmm.nasa.gov* and *https://pmm.nasa.gov/meetings/pmm-science-team-meetings*.

DAY ONE

The first day of the meeting began with a series of programmatic updates and status reports from NASA Headquarters (HQ) representatives and from NASA and Japanese GPM mission leadership, followed by presentations on GPM algorithm status and updates on applications related to PMM ST activities.

Programmatic Updates and Status Reports

Gail Skofronick-Jackson [NASA HQ—*GPM Program Scientist*] opened the meeting and welcomed the participants. She provided an update on the state of NASA's current and future Earth-observing fleet of satellites—particularly those that collect precipitation-related measurements. Related to this topic, Skofronick-Jackson discussed the 2017 NASA Earth Science

[1] TRMM data-gathering activities ended in 2015 after the platform was deorbited; however, data reprocessing continues.
[2] TRMM and GPM are partnerships between NASA and the Japan Aerospace Exploration Agency (JAXA), with more than 20 additional international partners. To learn more about GPM, see "GPM Core Observatory: Advancing Precipitation Measurements and Expanding Coverage" in the November–December 2013 issue of *The Earth Observer* [**Volume 25, Issue 6**, pp. 4-11—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/Nov_Dec_2013_final_color.pdf#page=4*] and "The Global Precipitation Measurement (GPM) Mission's Scientific Achievements and Societal Contributions: Reviewing Four Years of Advanced Rain and Snow Observations," at *https://doi.org/10.1002/qj.3313*.

[3] NASA's and JAXA's PMM science teams hold an invitation-only leadership board meeting designed to coordinate scheduling and approve joint TRMM and GPM mission activities and data products.
[4] CEOS is a consortium of roughly 60 agencies worldwide that work to ensure international coordination of civil, space-based, Earth-observation programs for the benefit of all. For more information, visit *http://ceos.org*.

Photo. The 2019 PMM STM attendees gathered in front of Indiana's Soldiers and Sailors Monument. **Photo credit:** Chris Kidd

Decadal Survey Report,[5] highlighting the recommended NASA flight program elements. She also provided an overview of investments that NASA HQ has made toward improving precipitation measurements. These include providing funding for Earth Science Technology Office (ESTO) Program Elements; the Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission,[6] and the Investigation of Microphysics and Precipitation for Atlantic Coast-Threatening Snowstorms (IMPACTS) mission.[7] She concluded with reports of PMM science activities during the 2018 fiscal year, emphasizing the 130 proposals submitted for the tenth PMM Science Team ROSES call, 40 of which have been selected for funding.[8]

Scott Braun [NASA's Goddard Space Flight Center (GSFC)—*GPM Project Scientist*] gave two presentations during the opening session. In the first presentation, he provided an overview of the current GPM Core mission, highlighting the spacecraft, its instrumentation, and algorithm development status. He noted that all systems are fully functional, with end-of-fuel predictions indicating the potential for orbital adjustments until the early 2030s. Braun also discussed aspects of the Core observatory's instrumentation, noting that the GPM Goddard Profiling Algorithm (GPROF) for the GPM Microwave Imager (GMI) is operating at version 5 (V05), and GPM's Dual-frequency Precipitation Radar (DPR), the combined radar and radiometer, and the Integrated Multi-Satellite Retrievals for GPM (IMERG) algorithms are operating at version 6 (V06). He added that the next algorithm reprocessing will take place in 2021. Braun finished with a discussion of how the NASA Goddard Earth Sciences Data and Information Services Center (GESDIC) supports PMM data for user assistance and outreach.

In Braun's second presentation, he gave an update on the Aerosols, Clouds, Convection, and Precipitation (ACCP) Designated Observable (DO) Study.[9] The goal of the ACCP study is to define science goals and enable applications to outline the geophysical parameters needed, the desired capabilities associated with those parameters, and the observing system approaches necessary to achieve them. Braun discussed the ACCP status and science plan for the next several years, including information about the ACCP science objectives, instrument architecture concepts, technology needed for the study, and the value framework approach used to determine relative impact of science objectives, applications, and cost and risk assessments.

Erich Stocker [GSFC—*GPM Deputy Project Scientist for Data*] discussed the status of GPM data products. He explained that GPM Core and constellation data products are provided through the Precipitation Processing System (PPS) STORM[10] system (after free registration). He announced that—for the first time since PMM data reprocessing began in 1997—the data product versions are different for radiometer and radar, where all radiometer products are at data product version V05 and all radar-based products are at data product version V06. He ended by reporting that the GPM project science team has decided to skip V06 for radiometer products that are at V05 and to have all data product versions be at V07 at the next reprocessing cycle, planned for 2021.

In the final three presentations in this section, Japanese partners provided updates on their PMM-related activities. **Riko Oki** [JAXA] discussed programmatic activities related to GPM, including science team selection. He noted a range of JAXA outreach activities including visualizations of DPR data[11] and viewing DPR data in virtual reality. Oki then announced that the Advanced Microwave Scanning Radiometer-3 (AMSR-3) will fly on the Greenhouse Gases Observing Satellite-2 (GOSAT-2) no earlier than 2022.

Takuji Kubota [JAXA] described the Global Satellite Mapping of Precipitation (GSMaP) merged multisatellite rainfall product,[12] which comes in versions both with and without rain gauge adjustments. He explained that the new version, scheduled for release

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

[6] TROPICS was selected as an Earth Venture Instrument–3 (EVI-3) mission in 2016 and is planned for launch in the 2022-2023 time frame. For an overview of TROPICS see *https://tropics.ll.mit.edu/CMS/tropics/pdf/nasaTropicsFactSheet.pdf*.

[7] IMPACTS is a NASA Earth Venture Suborbital mission to study snowstorms along the eastern seaboard of the U.S. Its first round of flights are taking place during January and February 2020.

[8] ROSES stands for Research Opportunities in Space and Earth Sciences, an omnibus solicitation mechanism that covers all four of NASA's Science Mission Directorate divisions, and includes many different science topics among its program elements (a.k.a., calls for proposals). For more information about the PMM Science Team ROSES, visit *https://gpm.nasa.gov/pmm-science-team/2019*.

[9] To learn more about ACCP, see "Summary of the NASA Weather and Air Quality Workshop" in the November–December 2019 issue of *The Earth Observer* [**Volume 31**, **Issue 6**, pp. 24–25—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Nov_Dec_2019_color_508.pdf#page=21*]. For more information, visit *https://science.nasa.gov/earth-science/decadal-accp*.

[10] STORM is a publicly available web-based data access interface for the GPM PPS. See *https://storm.pps.eosdis.nasa.gov* for more details.

[11] JAXA GPM visualizations can be viewed at *https://www.eorc.jaxa.jp/GPM/3DRAIN/index_j.html*.

[12] There are two multisatellite systems for processing precipitation data. The Japanese GSMaP system, discussed here, is separate from NASA's IMERG, discussed earlier (see Braun's summary, above).

in 2020, will be global in scope and will normalize retrieval estimates from different sensors using GMI and TRMM Microwave Imager (TMI) as a reference. Kubota concluded by noting that GSMaP has 5,380 users from 128 countries and is used for weather monitoring, flood warning and prediction, agricultural forecasting, and hydrological modeling.

Nobuhiro Takahashi [Nagoya University] summarized scientific studies in Japan using GPM data, including studies on microphysical properties of rain, latent heating, ground validation, data assimilation, and applications of machine learning. He also provided status updates for the DPR algorithm. He particularly focused on changes to the K_a-band swath, which in May 2018, was expanded to cover the entire K_u-band swath. Takahashi reported on the status of development of an experimental product that will process dual-frequency retrievals across the entire Ku-band swath. Lastly, he noted a scan-angle dependence of rainfall estimates in the outer swath, i.e., the new region of dual-frequency retrievals discussed above, which JAXA is working to correct.

Algorithm Status

Following the programmatic updates, the Algorithm Status session provided information and updates on various aspects of the five major algorithms associated with GPM observations used to produce calibrated, swath-level instrument data (Level-1 products) to gridded and accumulated precipitation products (Level-3 products).

Bob Meneghini [GSFC] discussed developments to the GPM radar algorithm, focusing on improvements to the surface reference estimates, comparing multiple approaches and the conditions under which they work best for improving estimates of path-integrated attenuation.

Bill Olson [GSFC] provided an update on the combined GPM retrieval algorithm V06X,[13] describing that this algorithm focuses on adapting to the new full swath K_a/K_u radar band measurements that Nobuhiro Takahashi described in his presentation. He concluded that the combined retrieval involves producing a precipitation profile and brightness temperature database for the radiometer retrieval algorithm, which will improve consistency between the combined and radiometer-only retrievals and simplify future development of radiometer-only databases.

Chris Kummerow [Colorado State University (CSU)] discussed developments and plans for the radiometer-only algorithm (i.e., GPROF). He noted that for GPROF 2021, the radiometer algorithm team is continuing to work on a number of known issues, including detecting snow and orographic precipitation, and convective vs. stratiform biases in retrieval estimates. They are also working to incorporate the operational NOAA Microwave Integrated Retrieval System (MIRS)[14] retrieval for nonprecipitating profiles in the database, noting that it should improve consistency between the precipitating and nonprecipitating regions.

George Huffman [GSFC—*GPM Deputy Project Scientist*] provided an update on the V06 IMERG algorithm that provides near global coverage at 10-km (6.2-mi) resolution—and which now extends back to June 2000. He noted that this version uses the combined radar-radiometer retrievals (e.g., CORRA)[15] to intercalibrate different sensor precipitation products.

Wei-Kuo Tau [GSFC] presented information on the convective stratiform heating (CSH) algorithm, mentioning several changes from V05 to V06 including a decrease in the model grid size from 1000 m (3280 ft) to 200 m (656 ft), changes to the convective/stratiform separation, and an improved CSH lookup table, based on results from 10 field campaigns.

PMM Applications Status and Reports

Day one concluded with a session focusing on current GPM applications status and projects.

Dalia Kirschbaum [GSFC—*GPM Deputy Project Scientist for Applications*] and **Andrea Portier** [GSFC/Science Systems and Applications, Inc. (SSAI)] presented an overview of current activities related to GPM applications, science, and outreach. They discussed the strategy for and approach to GPM applications, showcased multiple highlights of end-users integrating GPM data into their projects, and presented a summary of the 2019 NASA Weather and Air Quality Forecasting Workshop hosted by the GPM Applications team in July 2019 at the Earth System Sciences Interdisciplinary Center (ESSIC) in College Park, MD.[16] They concluded their presentation by highlighting multiple outreach activities marking

[13] For more information about V06X, download the file at *https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20190033254.pdf*.

[14] MIRS, run operationally by the National Oceanic and Atmospheric Administration (NOAA), is a physically-based microwave retrieval system designed to treat both atmospheric and surface parameters which affect passive microwave measurements. For more information, visit *https://www.star.nesdis.noaa.gov/mirs/index.php*.

[15] CORRA stands for Combined Radar Radiometer Analysis for both the TRMM and GPM eras. CORRA is discussed on page 7 of the document found at [*https://pmm.nasa.gov/sites/default/files/document_files/IMERG_ATBD_V06.pdf*], which is the Algorithm Theoretical Basic Document for V6 of IMERG.

[16] For more information, read "Summary of the 2019 NASA Weather and Air Quality Forecasting Workshop" in the November-December 2019 issue of *The Earth Observer* [**Volume 31, Issue 6**, pp. 21-26—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/Nov_Dec_2019_color_508.pdf#page=21*].

the release of IMERG V06 in October 2019,[17] which included data visualization products,[18] NASA Live Shots,[19] an applications webinar,[20] and GSFC Visitors Center Sunday Experiment[21] activity.

Ahmad Tavakoly [U.S. Army Engineer Research and Development Center] discussed enabling the integration of the U.S. Streamflow Prediction Tool (SPT) with GPM products to improve accuracy and delivery of analyses and forecasts of streamflow throughout the world.[22]

Mekonnen Gebremichael [University of California, Los Angeles (UCLA)] focused on the use of IMERG to develop precipitation forecasts for hydropower reservoir operations in Africa. **Chris Funk** [U.S. Geological Survey (USGS)/UC Santa Barbara (UCSB) Climate Hazards Center] presented his team's work to improve climate services in developing nations, using an enhanced IMERG-based Agricultural Outlook System, or AgOut, to support food security and agricultural applications in the developing world. Lastly, **Dan Wright** [University Wisconsin–Madison] presented work on characterizing the uncertainty of IMERG output in relation to identifying landslide hazards. He described how a Censor Shifted Gamma Distribution model that characterizes precipitation errors can be implemented within a landslide model that relies on IMERG rainfall and static susceptibility estimates to landslides in order to create a probabilistic estimate of landslide hazard dynamically. Wright presented results that show how the application of this error model can provide a range of possible precipitation amounts instead of the strict rainfall threshold that is currently employed within the landslide modeling efforts, and noted that it has application in other hazard application areas.

DAYS TWO AND THREE

The second and third days of the meeting featured a panel session that covered GPM's GV and field campaign activities, two presentation sessions providing updates from GPM's international partners, and five presentation sessions that focused on various aspects of PMM science.

Panel Discussion: Ground Validation and Field Campaigns

Joe Munchak [GSFC—*GPM Deputy Project Scientist for Ground Validation*] facilitated this discussion; he was joined by four panelists: **Sarah Ringerud** [GSFC/ESSIC], **Guosheng Liu** [Texas A&M Corpus Christi], **Patrick Gatlin** [NASA's Marshall Space Flight Center (MSFC)], and **Claire Pettersen** [University Wisconsin–Madison]. The discussion focused on how GV field activities and data play a role in verifying GPM's algorithms.

Munchak then provided a summary of field campaigns including the Midlatitude Continental Convective Clouds Experiment (MC3E) in Oklahoma in 2011; the GPM Cold-season Precipitation Experiment (GCPEx) in Ontario, Canada, in 2011-2012; the Iowa Flood Studies (IFloodS) in Iowa in 2013; and the Olympic Mountain Experiment (OLYMPEX) in Washington State in 2015.[23] He emphasized that direct validation and physical constraints derived from GV activities are needed for algorithms, where direct validation helps compare algorithm output to ground-based measurements and physical constraints help validate algorithm assumptions. The panelists then shared a few examples about how field campaigns have contributed to improving GPM algorithms.

Highlights from PMM International Partners

Two sessions were dedicated to a series of 10 presentations from GPM international partners, which included representatives from the French National Science Research Center, the Italian Institute of Atmospheric Sciences and Climate, Brazil's Center for Weather Forecast and Climatic Studies, and the Korean Meteorological Administration. The reports highlighted projects ranging from the contribution of rain gauges in the calibration of IMERG to current GV activities in Brazil and GV status in Korea. Other highlights covered instrument status and product updates including new developments to Version 2.0 of the Tropical Amount of Precipitation with an Estimate of ERrors (TAPEER) rainfall algorithm (released in June 2017), which shows promise for improving measurements over steep topography, and product updates of the Snow retrievaL ALgorithm fOr gMi (SLALOM) where the algorithm is doing a reasonable job of transferring the characteristics of CloudSat's Cloud Penetrating Radar (CPR) characteristics to the GMI datasets.

[17] To read about the release of Version 6 IMERG, visit *https://pmm.nasa.gov/articles/two-decades-imerg-resources*.

[18] To view these products, visit *https://svs.gsfc.nasa.gov/Gallery/IMERG.html*.

[19] Live Shots are live broadcasts of NASA scientists being interviewed by roughly 30 to 40 morning TV news teams. In this case, GPM scientists were interviewed to discuss the IMERG V06 product.

[20] The webinar can be viewed at *https://pmm.nasa.gov/training* and is titled "Introductory Webinar: Overview and Applications of Integrated Multi-Satellite Retrievals for GPM (IMERG) Long-term Precipitation Data Products."

[21] Sunday Experiment is a free monthly program offered at the GSFC's Visitor Center. Activities are best suited for children ages 5 to 10.

[22] SPT is used operationally for several regions worldwide to provide situational awareness in data-sparse areas. For more information, visit *https://streamflow-prediction-tool.readthedocs.io/en/latest*.

[23] *The Earth Observer* reported on several of these field campaigns when they occurred. Interested readers can search for archived issues at *https://eospso.nasa.gov/earth-observer-archive* using campaign-specific keywords.

Highlights from PMM Science Reports

The remaining five sessions focused on recent science results from PMM projects. Several themes emerged from these reports, including developments in hydrometeor scattering properties, validation methods for precipitation retrievals, and advancements made towards measuring precipitation in the tropics. To see the full list of reports please go to *https://pmm.nasa.gov/protected-page?destination=node/3033&protected_page=11*.

Ian Adams [GSFC] introduced the OpenSSP dataset, which is a catalog of synthetic ice and snow particles and the associated scattering properties that provides a recalculated library of hydrometeor single-scattering properties. Researchers are using this dataset to evaluate graupel contributions to multiple scattering, and there are goals to assess uncertainties originating in unknown habit mixtures and to model melting particles. **Efi Foufoula-Georgiou** [UC Irvine] discussed problems applying pixel-scale retrieval results for use in hydrological-scale purposes. She pointed out that single-pixel retrievals do not capture spatial structure, and increasing retrieval database size or adding ancillary data often does not improve variances in retrieved quantities. Lastly, **Anita Rapp** [Texas A&M University] discussed the variability in convective precipitation feature populations with the Inter Tropical Convergence Zone (ITCZ) width in the Pacific Ocean. She noted that the ITCZ widths decrease over time, and that a wider ITCZ is associated with larger and deeper GPM/TRMM precipitation features, while a narrower ITCZ comprises smaller, shallower systems. This result is different from recent research that hypothesizes stronger convection associated with a narrower ITCZ, and efforts to fully understand this finding are ongoing.

Another topic covered was improved methods for GPM algorithm retrievals of rain and snow and leveraging dual-frequency information. **Venkatchalam Chandrasekar** [CSU] described the use of the dual-frequency ratio (DFR), measured to identify the presence of graupel and hail, with validation showing high consistency between ground-based and space-based radar estimates of such occurrences. **Mircea Grecu** [Morgan State University] described a dual-frequency radar technique to retrieve snowfall across the full DPR swath. **Steve Nesbitt** [University of Illinois] concluded the session by discussing the use of GPM GV data to improve DPR precipitation estimates in ice and mixed-phase clouds.

Presentations in the Science Reports session also described advancements in data products and tools using GPM data. Specifically, **Min-Jeong Kim** [GSFC's Global Modeling and Assimilation Office (GMAO)] presented an overview of developing data-assimilated, four-dimensional (4D), global precipitation products from the Goddard Earth Observing System (GEOS) in support of the GPM mission. Specifically, she discussed that all-sky GMI observations were being implemented within the hybrid four-dimensional, ensemble-variational (4D-EnVar) algorithm in the GEOS Forward Processing (FP) system, which generates near-real-time atmospheric products using GEOS and distributes them to a broad community of users. Such usage increases not only the number of satellite observations being assimilated, but also the types of variables analyzed (e.g., hydrometeors such as liquid cloud, ice cloud, rain, and snow).

Toshi Matsui [GSFC/ESSIC] described the development of a quasipermanent GPM ground-validation supersite at NASA's Wallops Flight Facility. A goal for this project, titled the BiLateral Operational Storm-Scale Observation and Modeling (BLOSSOM) project, includes mapping combined *in situ*, radar, satellite, and cloud-resolving model data onto a uniform grid in a self-describing netCDF format, to enable users to easily access and manipulate the existing datasets.

Ralph Ferraro [NOAA/National Environmental Satellite, Data, and Information Service (NESDIS)'s Center for Satellite Applications and Research (STAR)] then followed with an update on NOAA's operational precipitation products and contributions made to PMM. He noted some instrumentation problems, including that the Advanced Technology Microwave Sounder (ATMS) instrument on NOAA/NASA's Suomi National Polar-orbiting Partnership (NPP) satellite has sporadic scan motor issues. Ferraro emphasized that this issue has no impact on the generated environmental data record or the sensor brightness temperature data record. He then summarized how PMM data are being used in NOAA's operational products, including the use of GPROF 2017 to support operational products from JAXA's Global Change Observation Mission-Water (GCOM-W) satellite, which includes NASA's Advanced Microwave Scanning Radiometer 2 (AMSR-2), and the use of GMI snowfall rates within NOAA's operational products.

Pierre Kirstetter [University of Oklahoma/NOAA] presented an assessment of the GPM Ground Validation Multi-Radar/Multi-Sensor (MRMS) system[24] for validating and improving GPM precipitation estimates, emphasizing that the system improves precipitation across Level 2 and Level 3 products and that GV can help lead the way toward improved GPM precipitation estimates.

The science reported on in this session also covered precipitation profiles and characteristics. **Mircea Grecu**, speaking on behalf of **Linette Boisvert** [GSFC],

[24] For more information about MRMS, visit *https://mrms.nssl.noaa.gov*.

focused on the potential linkage between decreases in Arctic sea ice and transport of water vapor into the polar region by extratropical cyclones. He noted that high-latitude water vapor, in its role as a greenhouse gas, may be acting to warm the Polar Regions, thereby contributing to ice-sheet shrinkage.

Lazaros Oreopoulos [GSFC] discussed relationships between NASA's Terra and Aqua Moderate Resolution Imaging Spectroradiometer (MODIS)-derived cloud cluster size distributions and IMERG-derived precipitation amounts, showing that moderate-sized clusters produced heavier precipitation compared to the largest cloud clusters. Statistics on feature height and feature echo height are also being assembled.

Gerald Heymsfield [GSFC] detailed a study using Weather Research and Forecasting (WRF) Model simulations and airborne observations from the Integrated Precipitation and Hydrology Experiment (IPHEx) and OLYMPEX field campaigns to provide improved understanding of microphysical and dynamical processes in wintertime and orographic precipitation.

Conclusion

Gail Skofronick-Jackson closed the meeting by thanking all the session chairs and speakers, emphasizing PMM's accomplishments and project findings during the 2018 fiscal year. She noted important directions for future PMM projects and encouraged the PMM ST to share scientific highlights and publications with her and the GPM management team. The next PMM STM will likely be held in late October 2020.

Acknowledgments: The authors would like to recognize the contributions made by **Scott Braun** and **George Huffman** [both at GSFC], **Steve Rutledge** [CSU], **Norman Wood** [University of Wisconsin–Madison], **Gregory Elsaesser** [NASA's Goddard Institute for Space Studies (GISS), Columbia University], **Wes Berg** [CSU], and **Dan Cecil** [MSFC] in preparing this article for publication in *The Earth Observer*. ■

NASA Lights the Way at the 2019 AGU Fall Meeting

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participate in a Terra Trivia game at the NASA exhibit that was created by the Earth Science Outreach Team at NASA JPL. To take the quiz, visit *https://climate.nasa.gov/quizzes/terra20*.

Many people have been involved with the success of the Terra mission over the past twenty years. On December 8, 2019, the Sunday evening before the AGU meeting began, over one hundred people filled the Savoy Ballroom at the Marriott Union Square hotel to share stories that led to Terra's success, and to celebrate the milestone of Terra's twentieth anniversary. **Kurtis Thome**, **Paula Bontempi**, **Jamie Wicks** [NASA HQ—*Program Executive for Operating Missions*], and **Jeanne Behnke** [GSFC] were among those who spoke.

Conclusion

The SSO plans to represent NASA at a variety of scientific venues and public events in the coming calendar year. Such outreach exhibits allow the agency to demonstrate its science activities in a single setting, often reaching thousands of people in a very short time. Currently, the Hyperwall and Dynamic Planet[4] provide exciting tools for NASA to communicate its science activities on a one-on-one basis. The team is eager to see what 2020—a year that sounds almost like a sci-fi fictional year—will bring! ■

[4] NASA's "Dynamic Planet" is a 48-inch spherical display system that provides a unique and vibrant global perspective on Earth, our Sun, various planetary bodies in our solar system, and the universe, to increase and improve public understanding of science. To learn more visit *https://eospso.gsfc.nasa.gov/content/dynamic-planet*.

Summary of the Fifth DSCOVR Science Team Meeting

Alexander Marshak, NASA's Goddard Space Flight Center, alexander.marshak-1@nasa.gov

Introduction

The fifth Deep Space Climate Observatory (DSCOVR) EPIC and NISTAR[1] Science Team Meeting (STM) was held at the Visitor Center of NASA's Goddard Space Flight Center (GSFC) from September 17-19, 2019, and was attended by over 50 people. While most participants were from GSFC, several were from other NASA centers, U.S. universities, and Department of Energy laboratories; there were also several European participants, from Finland, Germany, France, and Spain. A full overview of DSCOVR was given in the summary of the 2018 DSCOVR STM, and will not be repeated here.[2] This article presents the highlights of the 2019 meeting; the full presentations can downloaded from *https://avdc.gsfc.nasa.gov/pub/DSCOVR/Science_Team_Meeting_Sept_2019.*

Opening Presentations

The opening session consisted of a series of presentations from DSCOVR mission leaders and GSFC and NASA Headquarters (HQ) representatives, who gave updates on the mission and its Earth Science instruments—including DSCOVR's extended stay in safe mode since June 27, 2019, as well as reports on data product releases and mission reviews, both previous (End of Mission review) and upcoming (Senior Review).

Alexander Marshak [GSFC—*DSCOVR Deputy Project Scientist*] opened the meeting. He announced the release of EPIC Level-2 products and mentioned that the mission successfully passed its End of Prime Mission review. The team was directed to prepare and submit a proposal to the 2020 Earth Science Senior Review.[3] The review recommended that EPIC and NISTAR receive continued funding through FY20 for continued operations and data analysis.

Adam Szabo [GSFC—*DSCOVR Project Scientist*] reported on the current status of DSCOVR. He explained that the laser in the DSCOVR Miniature Inertial Measurement Unit (a.k.a., the "gyro") has suffered significant deterioration preventing the spacecraft from relying on spacecraft three-dimensional attitude information coming from it. This necessitated placing the spacecraft in *safe mode*—where the spacecraft points at the Sun (the only direction that the Sun sensors can determine) keeping the spacecraft power positive. While the spacecraft is in this orientation, Earth is not in the field of view of the EPIC camera or the high-gain antenna, which prevents the continued collection of EPIC and NISTAR data. The DSCOVR team has been working to modify the flight software to rely exclusively on star tracker information to orient the spacecraft correctly. The flight software development is on schedule and it is expected that DSCOVR will return to full operations on March 1, 2020, or shortly thereafter.

Jim Irons [GSFC—*Director for the GSFC Earth Sciences Directorate*] welcomed meeting participants to GSFC. Irons noted that in the mid-1990s he closely followed the development of the mission, which was originally called "Triana" and is glad to see DSCOVR flying and providing unique data. He mentioned that this is an exciting time for DSCOVR's Earth-viewing instruments as products have been released and the broader science community has been engaged through these products.

Richard Eckman [NASA Headquarters (HQ)—*DSCOVR EPIC/NISTAR Program Scientist*] welcomed the returning and new members of the Science Team, who were selected through a solicitation in ROSES-18. He noted that the Senior Review process, for which DSCOVR will again be considered, will kick off in mid-December. He looked forward to the learning about recent accomplishments from Science Team members, which will be essential in assessing the mission's performance.

Updates on Science Operations, Data Products and Processing, and the Mission Website

The current safe hold notwithstanding, the DSCOVR mission components continue to function nominally, with progress being reported on several fronts, including data acquisition, processing, archiving, and release of new versions of several data products—e.g., see **Figure** on page 30. The number of users is increasing, with a new Science Outreach Team having been put in place to aid users in several aspects of data discovery, access, and user friendliness. System-level description of EPIC Level-1a (L1a) data calibration shows the instrument

[1] EPIC stands for Earth Polychromatic Imaging Camera; NISTAR stands for National Institute of Standards and Technology Advanced Radiometer. EPIC and NISTAR are the two Earth-observing instruments on DSCOVR.
[2] For details, see "Summary of the DSCOVR EPIC and NISTAR Science Team Meeting" in the November–December 2018 issue of *The Earth Observer* [**Volume 30**, **Issue 6**, pp. 16-22—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Nov_Dec_2018_color508_0.pdf#page=16*].
[3] **UPDATE**: The proposal will be submitted to NASA HQ in February 2020.

Figure. An EPIC image obtained on June 27, 2019—just before DSCOVR was placed in safe mode. **Image credit**: NASA

is responding nominally. Description of some of the presentations in this session are provided in **Table 1.**

EPIC Calibration

Scientific results from EPIC data have been improved owing to calibration activities, which covered flat-field calibration that led to ozone retrieval improvements, improved channel calibration coefficients, and the use of lunar observations for calibration trending.

Liang-Kang Huang [GSFC/Science Systems and Applications, Inc.] presented an update on efforts to calibrate the DSCOVR EPIC ultraviolet (UV) channels. The Version 3 (V3) EPIC L1a processing includes a new flat-field calibration that has led to subsequent improvements in ozone retrieval.

Igor Geogdzhayev [Columbia University] presented an update on calibration efforts for the EPIC visible and near-infrared (NIR) channels. He described an improved method to derive calibration coefficients for four EPIC visible and NIR channels based on comparison with Moderate Resolution Imaging Spectroradiometer (MODIS) L1B 1-km reflectances. Based on V3 data for 2017, the EPIC calibration factors were shown to agree to the previously published values within 1.5%.

Matthew Kowalewski [GSFC/USRA] discussed calibration of the EPIC oxygen (O_2) absorption bands, which use periodic observations of the Moon for calibration trending purposes. These lunar observations were also used to derive and trend the EPIC O_2 band relative calibration factors in order to complete the derivation of the visible absolute calibration coefficients. The relative calibration between the O_2 bands is stable and consistent between V2 and V3 of the L1a data, so no absolute calibration adjustments are needed between V2 and V3 L1a data products.

Status of NISTAR

Alhough the current DSCOVR safe hold inhibits collection of new science data, as with EPIC, NISTAR remains fully functional. With regard to data collected before June 2019, there are some disagreements between NISTAR and Clouds and the Earth's Radiant Energy

Table 1. Updates on DSCOVR science operations, data products and processing, and the mission website.

Presenter [Affiliation]	Topic/Title	Summary Findings
Carl Hostetter [GSFC]	DSCOVR Science Operations Center (DSOC) Level-0 (L0) to L1A/B	Described end-to-end system data acquisition and processing flow; gave an update on status of EPIC Version 3 (V3) and NISTAR V2.1 reprocessing.
Marshall Sutton [GSFC]	EPIC L2 Processing	Discussed generating and archiving EPIC L2 products.
Karin Blank [GSFC]	Empirical Signal Retrieval in NISTAR data	Reported on the newest version of the L1 data (Version 3), with improved geolocation conformity with L1 data requirements.
Walt Baskin and **Danielle Groenen** [NASA's Langley Research Center (LaRC)]	ASDC DSCOVR Update	Presented use and dataset download statistics; described newly formed Science Outreach Team to facilitate data discovery, access, and analysis.
Matthew Kowalewski [GSFC/Universities Space Research Association (USRA)]	DSCOVR L1a Calibration Update	Summarized in-flight Earth observations and calibration measurements and instrument's nominal health and performance.

System (CERES) data.[4] The presentations in this session explored possible explanations for such discrepancies. The presentation summaries in this section provide more details on specific topics related to NISTAR.

Allan Smith [L1 Company] explained that the NISTAR radiometric scale had been revised to accommodate an older ground calibration and a fix for a transient in the shutter-modulated Earth signal that induces an error in the demodulated signal, bringing the NISTAR shortwave (SW) measurements closer to those of CERES.

Wenying Su [LaRC] described an effort to determine daytime radiative fluxes from DSCOVR observations. EPIC composite data were developed to map the low-Earth-orbit (LEO)/geostationary-Earth-orbit (GEO) cloud properties and other ancillary data into the EPIC pixels to provide scene identification. Su explained that they developed algorithms to derive global daytime mean SW fluxes from EPIC observations by employing narrowband-to-broadband regressions and global anisotropic factors. These EPIC-based SW fluxes agreed with CERES Synoptic Radiative Fluxes and Clouds (SYN) SW[5] fluxes to within ±3%. EPIC VIS and NIR bands exhibit excellent radiometric stability over time, and the EPIC V3 navigation was much improved.

Clark Weaver [University of Maryland, College Park (UMD)] discussed results of a comparison of SW flux measurements derived from NISTAR data to those derived from CERES and EPIC data. He explained that to account for the light reflected in the direction of the NISTAR instrument, each CERES grid cell was multiplied by an anisotropy factor taken from the CERES Angular Distribution Models (ADM). The NISTAR estimate was higher than that for CERES. However, Weaver said that there were differences between theoretical and observed values, and estimated that the CERES anisotropy is low by 5 to 10 W/m^2, which reduces the disparity between the NISTAR and CERES measurements.

Andrew Lacis and **Barbara Carlson** [both at NASA's Goddard Institute for Space Studies (GISS)] discussed research aimed at using NISTAR spectral ratio measurements as unique diagnostic constraints on radiative transfer algorithms in climate general circulation models (GCM). The results show that the NISTAR NIR/visible (VIS) spectral ratio data of the Earth's sunlit hemisphere exhibits strong diurnal change with a characteristic seasonal variability. While the GCM spectrally integrated results appeared to be in reasonable agreement with CERES data, the NISTAR/GCM spectral ratio comparisons clearly point to some inadequacy in GCM parameterizations.

Daniel Feldman [Lawrence Berkeley National Laboratory] presented results from a study of the diurnal cycle of reflected shortwave radiation (RSR) based on CERES SYN, EPIC-derived fluxes, and NISTAR-derived fluxes. The analysis showed that the magnitude of the diurnal cycle of RSR was similar for CERES and EPIC but higher for NISTAR, though all products exhibited similar power spectral density curves, which indicates that the CERES diurnal filling algorithm, which had previously only been tested with GERB data, is robust.[6]

Status of EPIC Data Products

The presenters who spoke during this session gave updates on the status of and/or science results obtained using the various EPIC L2 data products. Most of these products were generated and their first version was released to the public through LaRC's Atmospheric Science Data Center (ASDC) between November 2017 and June 2018, and reported on in the 2018 DSCOVR STM Summary. **Table 2** on pages 32-33 summarizes the presentations given during this session. For more details, refer to the original presentations via the URL referenced in the Introduction.

Science from DSCOVR/EPIC Data

Harshvardhan Harshvardhan [Purdue University] studied a severe dust outbreak in the Arabian Peninsula using surface and satellite data as well as a simulation with a chemistry transport model. The model was able to reproduce the peak of the event as observed at the Mezaira, United Arab Emirates, AERONET site. EPIC-derived, 500-nm AOD tracked well with AERONET—but consistently underestimated AOD values. By contrast, MODIS and VIIRS AOD retrievals saturate at lower AOD and are thus not suitable for assessing simulations of extreme dust outbreaks.

Omar Torres [GSFC] showed results from a study in which he and colleagues explored the unprecedented amounts of tropospheric carbonaceous aerosols generated by wildfires in British Columbia in August and September 2017. EPIC observed the evolution of the aerosol plume for about six weeks from the onset of the wildfires. EPIC's characterization was based on the qualitative UV Aerosol Index (UVAI) and quantitative aerosol AOD and SSA estimates. EPIC achieves near-hourly retrievals of AOD, which allowed Torres and his colleagues to observe an calculate the diurnal evolution

[4] There are two CERES instruments on both Aqua and Terra. A single CERES instrument also flies on NASA's Suomi National Polar-orbiting Partnership (NPP) mission and on the NOAA-20 satellite.

[5] The CERES SYN SW data product contains a day of space- and time-averaged data from CERES for a single scanner instrument.

[6] GERB stands for Geostationary Earth Radiation Budget (GERB) instruments, which fly on EUMETSAT's series of Meteosat Second Generation (MSG) satellites. EUMETSAT is defined on page 43.

continued on page 33

Table 2. Status of EPIC data products.

Presenter [Affiliation]	EPIC Data Product(s)	Summary Findings
Natalya Kramarova [GSFC]	Total Ozone (O_3)	Discussed reprocessing the total ozone dataset using the new version 3 of L1 data and updated UV calibrations. In addition, the team plans to utilize the EPIC cloud pressure product derived from oxygen A-band in the ozone retrieval algorithm, as preliminary analysis shows such a switch brings improvements in the hourly total ozone product—especially for features on a smaller spatial scale.
Kai Yang [UMD]	Total O_3, Volcanic Sulfur Dioxide (SO_2), and Aerosol Index (AI)	Discussed status of listed products. Summarized the validation study, which shows that the ozone product is accurate, capturing the short-term variability and long-term consistency of global ozone distribution. Highlighted EPIC's unprecedented observations of volcanic plumes with short cadence and high sensitivity.
Simon Carn [Michigan Technological University]	Volcanic SO_2	Presented observations of recent volcanic eruptions, including the major eruption in the Kuril Islands (Russia) in June 2019—which was fortuitously captured just a few days before the DSCOVR safehold. Data showed the separation of SO_2 and volcanic ash components in the volcanic cloud during the eruption.
Hiren Jethva [GSFC/ Universities Space Research Association]	Near-UV Aerosol Optical Depth (AOD) and Single Scattering Albedo (SSA)	Showed results on diurnal variability of derived AOD over several global sites. Stated that retrieved products are in good agreement with ground-based Aerosol Robotic Network (AERONET) sun photometer measurements, and that research-level retrieval of cloud AOD provided consistent results when compared against equivalent airborne measurements carried out during ORACLES* campaign.
Alexei Lyapustin [GSFC]	Atmospheric Correction	Described the current status of MAIAC** EPIC Atmospheric Correction, released in February 2018. Gave an overview of the V2 MAIAC product suite, and described the ongoing validation activities of AOD both over land and ocean. Described new algorithms to derive both AOD and spectral absorption from combining visible and UV measurements.
Yuekui Yang [GSFC]	Cloud Products	Described significant progress in cloud detection over snow and ice, utilizing an improved algorithm that uses the EPIC O_2 A- and B-band measurements, with significant improvements over the current algorithm.
Yaping Zhou [USRA]	Cloud Detection over Snow and Ice	Discussed developing an elevation and zenith-angle-dependent threshold scheme, with significant improvement over the existing algorithm that imposes fixed thresholds for A- and B-band ratios.
Robert Frouin [University of California, San Diego]	Ocean Surface Photosynthetically Active Radiation (PAR)	Described a new algorithm created to estimate daily mean PAR at the ocean surface from specific spectral bands. The first daily PAR imagery shows good agreement with operational estimates from sensors in polar and geostationary orbits.

table continued on next page

Table 2. Status of EPIC data products (*continued*).

Presenter [Affiliation]	EPIC Data Product(s)	Summary Findings
Yuri Knyazikhin [Boston University]	Vegetation Earth System Data Record (VESDR)	VESDR was provisionally released in June 2018, with modifications to the operational algorithm to eliminate retrieval instabilities for solar zenith angles greater than 55°; also described new vegetation parameters—Earth Reflector Type Index (ERTI) and Canopy Scattering Coefficient—at EPIC spectral bands.
Xiaojun She, Yuri Knyazikhin and Ranga Myneni [all at Boston University]	Vegetation Hot Spot Signatures	Described using different observation geometries that result in a new hot spot signatures that are maximally sensitive to vegetation changes.

*ORACLES stands for ObseRvations of CLouds above Aerosols and their intEractionS. This is an ongoing NASA Earth Venture Suborbital mission/field campaign.

**MAIAC stands for Multi-Angle Implementation of Atmospheric Correction.

of AOD. The unusually high UVAI pointed to an elevated aerosol layer well above the tropopause with over 250 kt of carbonaceous aerosol material injected at least 22 km (14 mi) into the troposphere over a three-day period.

Jun Wang [University of Iowa] presented his team's recent work of using EPIC O_2 A and B bands to retrieve smoke plume heights over both ocean and vegetated surfaces. He showed the retrieved layer heights for smoke particles are in good agreement with coincident CALIOP[7] observations, and are useful to supplement aerosol optical depth also retrieved from EPIC to map surface Particulate Matter ($PM_{2.5}$) concentration. He also presented the first results of smoke layer height retrieval from TROPOMI,[8] which is an example of what has been learned from EPIC observations that is being applied to other sensors.

Victor Molina Garcia [German Aerospace Center] presented preliminary results on the use of Optical Cloud Recognition Algorithm (OCRA) and Retrieval of Cloud Properties using Neural Networks (ROCINN) to estimate cloud properties from DSCOVR/EPIC measurements. For this purpose, they developed a georegistration-fix algorithm with unsupervised computer vision techniques, which improves the geolocation alignment of the Level 1B V2 imagery from 5 pixels to approximately 1.5 pixels.

Guoyong Wen [USRA] and colleagues showed that the vector composed of blue and NIR reflectance follows a nonlinear, counterclockwise, closed-loop trajectory from 0 to 24 UTC as Earth rotates—not observed by other LEO or GEO satellites due to their limited spatial or temporal coverage. Clouds play an important role in the nonlinear relationship, as does the well-known cloud-free, land–ocean reflectance contrast in the two bands.

Tamás Várnai [University of Maryland, Baltimore County (UMBC)] and colleagues discussed EPIC observations of sun glint and demonstrated that EPIC data at O_2 A-band absorption bands make it possible to distinguish glints off the ocean surface from glints off horizontally oriented ice crystals that float in marine ice clouds, which are ubiquitous, small, and bright. Varnai described the spectral characteristics of glints, and pointed out that EPIC data can help constrain the radiative effects of horizontal ice crystals causing the glints. He also demonstrated that the observed position of glints can help testing the accuracy of EPIC geolocation, even far from coastlines.

Presenting remotely, **Yongzhen Fan** [Stevens Institute of Technology] reported on his team's work on retrievals of aerosol and ocean products from EPIC using machine learning methods. He discussed a new multilayer neutral network (MLNN) atmospheric correction (AC) developed by their team. The MLNN AC algorithm is based on the spectral similarity between Rayleigh-corrected, top-of-the-atmosphere radiances and water-leaving radiances and doesn't require the aerosol properties to be retrieved. The algorithm relies on extensive and reliable simulations from a coupled atmosphere-ocean radiative transfer model. Fan closed by showing a daily composite of the EPIC ocean color and AOD products produced by the MLNNAC algorithm.

Jerald Ziemke [USRA] and colleagues derived tropospheric ozone maps from DSCOVR/EPIC combining EPIC total ozone measurements with MLS[9] ozone

[7] CALIOP stands for Cloud–Aerosol Lidar with Orthogonal Polarization, which flies on the NASA/Centre National d'Études Spatiales (CNES) Cloud–Aerosol Lidar and Infrared Pathfinder (CALIPSO) satellite.

[8] TROPOMI stands for TROPOspheric Monitoring Instrument, which flies on the European Space Agency's Copernicus Sentinel-5 Precursor satellite.

[9] MLS stands for Microwave Limb Sounder, which flies on NASA's Aura satellite.

profiles assimilated by the Global Modeling and Assimilation Office (GMAO). The derived tropospheric ozone provides synoptic maps every 1-2 hours—results never before achieved with satellite measurements. The derived tropospheric ozone—with high temporal resolution—is useful for studying effects on ozone from changing weather systems and other variabilities from short subdaily to daily timescales.

Karri Muinonen [University of Helsinki (UH)/Finnish Geospatial Research Institute, Finland] and **Olli Ihalainen** [UH] addressed retrievals of Earth's *momentary spherical albedo*[10] developed using DSCOVR/EPIC observations. EPIC is currently the only instrument that can simultaneously image Earth's entire illuminated disk, and allows for the radiative classification of the land, sea, and Arctic and Antarctic regions on the disk, accounting for the cloud deck. Earth's albedo can be retrieved from a combined effort of imaging with the EPIC camera, and modeling Earth *radiation pressure forces*[11] acting on space-geodetic satellites. Encouraging preliminary simulations were shown based on such Earth-disk classification and based on the subsequent radiation-pressure force exerted on six European Global Navigation Satellite System satellites.

Dalei Hao [Chinese Academy of Sciences/Joint Global Change Research Institute, Pacific Northwest National Laboratory] and colleagues discussed an unprecedented opportunity of EPIC observations to obtain global estimates of SW and PAR accurately at a high temporal resolution of about 1-2 hours. In the study, Hao and his colleagues developed and used a "random forest" model to estimate global hourly SW and PAR at high spatial resolution based on EPIC measurements. The EPIC SW and SW and photosynthetically active radiation (PAR) estimates provide a unique dataset with high accuracy for characterizing the diurnal cycles and their potential impacts on photosynthesis and evapotranspiration processes.

[10] The spherical albedo describes the ratio of the total radiative flux reflected by the planet to the total solar flux incident on the planet. The radiative fluxes are integrated over the UV, VIS, and NIR parts of the spectrum. *Momentary* refers to the idea of obtaining a time series of spherical albedo, i.e., the albedo is retrieved for each EPIC imaging sequence of 10 channels.

[11] Radiation pressure force is a generalized force caused by reflection, emission, and absorption, that derives from momentum exchange between an object (in this case, a spacecraft) and the local electromagnetic field.

Jay Herman [UMBC] derived erythemal irradiance at the ground using a fast algorithm described in a recently published paper (*https://doi.org/10.5194/amt-11-177-2018*) to obtain the distribution over the entire globe from sunrise to sunset. The results show the wide range of intensities ranging up to UV index (UVI) of 18 at elevated city sites, such as La Paz, Bolivia. Typical summer noon values for Greenbelt, MD, are UVI=6 with an occasional higher value of 8. The calculation includes the important effects of cloud cover altitude.

Alfonso Delgado Bonal [NASA Postdoctral Program] and **Alexander Marshak** used EPIC images, combined with ancillary information from EPIC on daytime variability of cloud fraction, at different local times during the last four years. That capability of capturing different moments of the day in a single picture allowed them to study the daily behavior of cloud fraction. They found that, in general, cloud fraction over the ocean is higher in the early morning and late afternoon, while at a minimum during the middle of the day. In contrast, the behavior over land is generally flat, with a very slight increase in the afternoon.

Conclusion

At the end of the meeting **Alexander Marshak, Jay Herman,** and **Adam Szabo** discussed adding content to the EPIC website: e.g., new L2 products such as ocean PAR and aerosol height, daily fluctuation of different products (e.g., cloud and aerosol properties, surface reflectance, ozone), and the possibility of designing and making gridded L3 products available to the scientific community. There was also a discussion of the operational characteristics of the EPIC instrument, particularly the signal to noise properties of bright and dark scenes.

The meeting was very successful and provided an opportunity to learn the status of EPIC and NISTAR—the Earth-observing instruments on DSCOVR, the status of recently released L2 data products, and the science results being achieved from L1. The next STM will be held in the fall of 2020 and it will be open to the general public. ■

NASA's Operation IceBridge Completes Eleven Years of Polar Surveys

Jessica Merzdorf, NASA's Goddard Space Flight Center, jessica.v.merzdorf@nasa.gov

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

For eleven years, from 2009 through 2019, the planes of NASA's *Operation IceBridge* flew above the Arctic, Antarctic, and Alaska, gathering data on the height, depth, thickness, flow, and change of sea ice, glaciers, and ice sheets.

Designed to collect data during the years between NASA's two Ice, Cloud, and land Elevation Satellites, (ICESat and ICESat-2), IceBridge made its final polar flight in November 2019, one year after ICESat-2's successful launch.

As the team and planes move on to their next assignments, the scientists and engineers reflected on a decade of IceBridge's most significant accomplishments.

2009: IceBridge's Launch and First Flights

NASA's ICESat monitored ice, clouds, atmospheric particles, and vegetation globally beginning in 2003. As ICESat neared the end of its life, NASA made plans to keep measuring ice elevation with aircraft until ICESat-2's launch. ICESat finished its service in August 2009, and IceBridge took over land and sea ice measurements for the next decade.

The number and models of IceBridge aircraft changed from year to year, and they carried more than a dozen instruments: from elevation-mapping lasers and ice-penetrating radars, to optical and infrared cameras, to gravimeters and magnetometers that reveal information about the bedrock under the ice. Beyond simply bridging the altimetry gap, the mission's comprehensive suite of instruments allowed it to document fast and slow changes to the ice sheets, understand the geophysical causes of those changes, track yearly fluctuations in sea ice thickness, and improve computing and modeling tools for research.

Before IceBridge, NASA was annually monitoring vulnerable areas of the Greenland Ice Sheet via the Arctic Ice Mapping Project (AIM). But IceBridge far surpassed previous campaigns in size and scope, with annual surveys of both poles, more instruments, and a longer time frame that allowed it to track changes across and even within years.

One of IceBridge's first important contributions was mapping hundreds of miles of *grounding lines* in both Antarctica and Greenland. Grounding lines are where a glacier's bottom loses contact with the bedrock and begins floating on seawater—a grounding line that is higher than the rock that the ice behind it is resting on increases the possibility of future unstable retreat.

"Before IceBridge, we had a lot of glaciers where we didn't have information on their grounding lines, which made it challenging to model them and develop reliable projections of sea level rise," said **Michael Studinger** [NASA's Goddard Space Flight Center (GSFC)], team lead for the Airborne Topographic Mapper (ATM) instrument and IceBridge's project scientist from 2010 to 2015.

The team mapped 200 glaciers along Greenland's coastal areas over their decade of work, as well as coastal areas, the interior of the Greenland Ice Sheet, and high-priority areas in Antarctica. "We asked, 'How will this look in 2030 or a hundred years from now?'" Studinger said.

2011: Antarctic Glacier Rifts and Calving Events

The team's expertise and adaptability enabled them to quickly modify flight routes as needed. During their 2011 Antarctic survey, IceBridge scientists spotted a massive crack in Pine Island Glacier, one of the fastest-changing glaciers on the continent. They later returned to study it more closely, and the crack produced a new glacier that October. This nimbleness made IceBridge uniquely versatile and responsive to the needs of the science community, enabling more science than their baseline assignments.

Pine Island has grown thinner and more unstable in recent decades, now generating new icebergs almost every year. IceBridge monitored Pine Island and other Antarctic glaciers for over a decade, watching for cracks that could lead to icebergs and using radar and gravimeters to map features like the deep water channel underneath Pine Island Glacier, which may bring warm water to its underside and make it melt faster.

"We need measurements to understand Antarctica's ice today and models to understand its future, which ultimately affects us all via sea-level change," said **Joe MacGregor** [GSFC—*Operation IceBridge Project Scientist*]. "Precisely measuring which Antarctic glaciers are thinning right now—and watching how they evolve over several years—helps us improve those models. Most of the biggest changes in Antarctic ice are occurring in

West Antarctica, and unfortunately, that ice is very likely to continue thinning for the foreseeable future."

2013: Looking Below the Ice—At Both Poles

In 2013, scientists from the British Antarctic Survey released an updated map of the bedrock beneath the Antarctic Ice Sheet—see **Figure**. The model included surface elevation, ice thickness, and bedrock topography data from ICESat, IceBridge, and missions from international partners.

Understanding what kind of rock lies beneath an ice sheet can yield important clues about how the ice on top might flow and change, said Studinger.

"Gravity and magnetic measurements provide you with constraints to infer what kind of rock you have below an ice sheet," he said. "That matters for the way and speed the ice is flowing. If you have soft sediment rock, that and meltwater can be a lubricant for an ice sheet. Crystalline rock, like granite, is harder to turn into a lubricant, making it more challenging for an ice sheet to develop a fast flow."

Carried by its own weight and the dynamics of the ground or water beneath it, ice flows toward the ocean, eventually floating offshore and potentially breaking off into icebergs, like those of the Pine Island Glacier. The better scientists understand this flow, the better they can model how it might progress in the future. IceBridge's array of instruments measuring the top, middle and bottom of the Antarctic ice sheet are uniquely suited to studying this process, said Studinger.

"Having all these pieces of information together is incredibly valuable, and we repeat the measurements year after year so we can see how things change over time," he said. "That is a tremendous data asset and something we can't do from space."

Sometimes measuring the unseen bedrock not only helps explain known processes, but also yields new surprises. Researchers from the University of Bristol used decades of airborne radar data—much of it from IceBridge—to map the bedrock underneath the Greenland Ice Sheet. They found a previously unknown canyon more than 400 mi (643 km) long and up to a 0.5 mi (0.8 km) deep slicing through the northern half of the country.

The scientists believe the canyon—dubbed the "Grand Canyon" of Greenland—may have once been a river system, and today likely transports subglacial meltwater from Greenland's interior to the Arctic Ocean.

2015: It's What's Inside (the Ice Sheet) that Counts

After mapping the bedrock under the Greenland Ice Sheet, scientists turned their attention to the middle layers of the ice. Using both ice-penetrating radar and ice samples taken in the field, MacGregor and his team created the first map of the ice sheet's many layers, formed as thousands of years of snow became compacted downward and formed ice.

As with all models, a better understanding of the past means more robust predictions of the future. Measuring past melt, accumulation and flow helps glaciologists refine their models of the Greenland Ice Sheet's future.

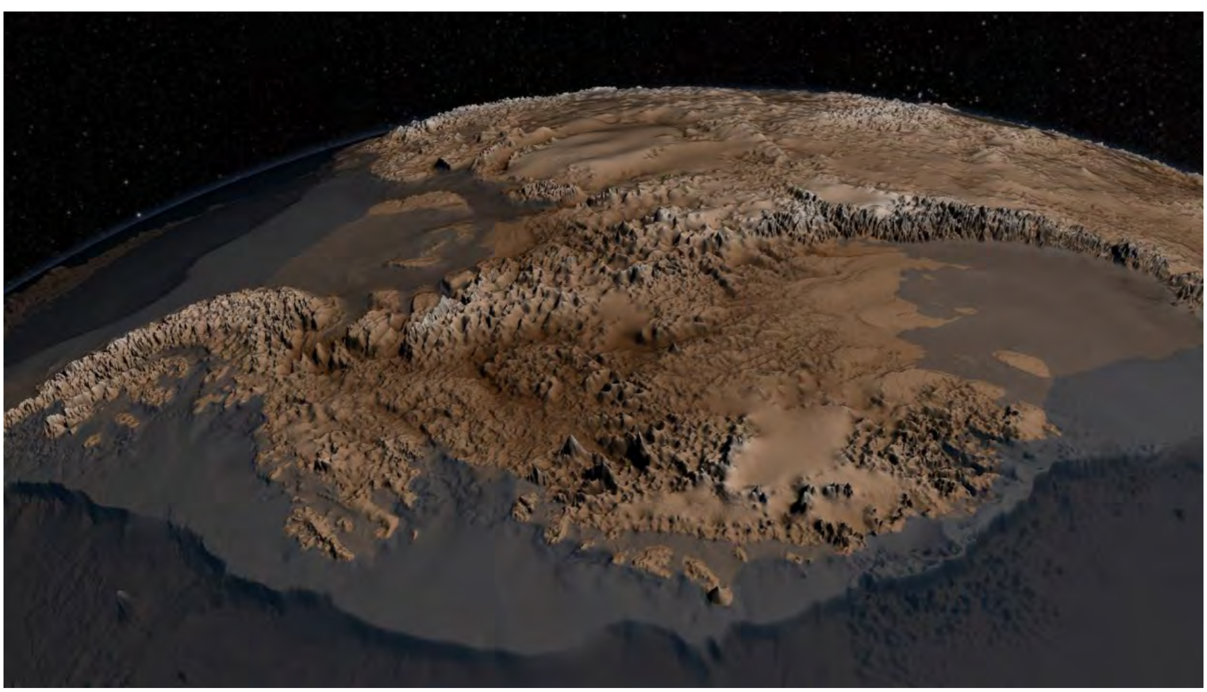


Figure. This bedrock map of Antarctica developed in 2013 from IceBridge and other data was far more detailed than previous maps, giving researchers and modelers new information about how ice flows or sticks on the rock below the Antarctic ice sheet. **Image credit:** NASA/Cynthia Starr

"Getting a sense of how old Greenland's ice is at different depths across the island allowed us to peer into its past," said MacGregor. "Making the three-dimensional map of Greenland's ice layers enabled us to discover that the ice sheet has slowed down over the last several thousand years. It also gave us clues as to how the ice sheet has warmed in the past, and where it may be frozen to bedrock or slowly melting instead."

2018: Completing the Data Bridge

ICESat-2 was launched from California's Vandenburg Air Force Base on September 15, 2018, rocketing IceBridge into the final phase of its mission: Connecting ICESat and ICESat-2.

IceBridge continued collecting data after ICESat-2's launch, its primary function being to validate the new satellite's measurements. By conducting precise *underflights*, where planes traced the satellite's orbit lines and took the same measurements at nearly the same time, the science teams could compare results and make sure ICESat-2's instruments were functioning properly.

Normally, IceBridge flights were conducted in full daylight, for maximum visibility. But during the satellite underflights, the planes also took measurements at dusk, to look for changes in accuracy with lower light. They also measured so-called *blue ice*, or ice not covered by snow, to better understand how the lasers penetrated ice.

IceBridge also underflew a number of European satellites during its ten years, like the European Space Agency's (ESA) CryoSat-2 and Copernicus Sentinel-3 satellites, and overflew ground campaigns like ESA's CRYOsat Validation EXperiment (CryoVEx) campaign and the Danish Programme for Monitoring of the Greenland Ice Sheet (PROMICE) weather stations. Its precise, reliable measurements provided a standard to help other missions ensure high-quality measurements of their own.

2019: The End of an Era

In 2019, IceBridge continued flying in support of ICESat-2 for its Arctic and Antarctic campaigns. The hundreds of terabytes of data the team collected over the decade will fuel science for years to come.

"This data doesn't get old," Studinger said. "This dataset we have right now will be incredibly valuable going into the future. It's basically the only dataset of its kind that we have."

"Our data are freely available to anyone," said **Eugenia DeMarco** [GSFC—*Operation IceBridge Project Manager*]. "I believe that, as humans, we are stewards of this planet, and as such, it is our responsibility to take care of it. The first step in that process is to find out what's going on with the physical world so we can better address the challenges facing our planet. I believe IceBridge and the data it has collected help answer the question of what's going on, and that is one of the biggest contributions IceBridge has provided over the years."

The campaign completed more than 900 flights between Greenland and Antarctica, and more than 150 in Alaska. While some members of the team changed over the decade, some have been with the project since its beginning.

"We had this incredible can-do attitude on both the instrument teams and the aircraft teams," said Studinger, who was the first ICESat Project Scientist in 2009 and worked with the mission throughout the decade. "We might have been working really long days for 11 weeks straight in Greenland, but still, at 5 in the morning, people step on the airplane and say hello with a big smile on their face. It really speaks to the people, who for me, were the most enjoyable part—the IceBridge family."

IceBridge finished its last polar flight on November 20, 2019. The team will complete one more set of Alaska flights in 2020.

"Operation IceBridge took what NASA had already learned how to do with planes at the poles and supersized it, with consistently successful airborne campaigns across the Arctic and Antarctic for eleven years straight," said MacGregor. "While IceBridge was laser-focused on its primary objective—bridging the gap between ICESat and ICESat-2—it was sufficiently big and broad in scope that it generated a momentum all its own, too. IceBridge opened the door to new ways of thinking about monitoring the polar regions and enabled numerous unexpected discoveries, and brought new scientists and new data types into the fold." ■

Greenland's Rapid Melt Will Mean More Flooding

Arielle Samuelson, NASA/Jet Propulsion Laboratory, arielle.a.samuelson@jpl.nasa.gov

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

The Greenland Ice Sheet is rapidly melting, having lost 3.8 trillion tons of ice between 1992 and 2018, a new study from NASA and the European Space Agency (ESA) finds. The study combined 26 independent satellite datasets to track global warming's effect on Greenland, one of the largest ice sheets on Earth, and the ice sheet melt's impact on rising sea levels. The findings, which forecast an approximate 3 to 5 in (70 to 130 mm) of global sea level rise by 2100, are in alignment with previous worst-case projections if the average rate of Greenland's ice loss continues.

Changes to the Greenland and Antarctic ice sheets are of considerable societal importance, as they directly impact global sea levels, which are a result of climate change. As glaciers and ice sheets melt, they add more water to the ocean. Increasing rates of global warming have accelerated Greenland's ice mass loss from 25 billion tons per year in the 1990s to a current average of 234 billion tons per year. This means that Greenland's ice is melting on average seven times faster today than it was at the beginning of the study period. The Greenland Ice Sheet holds enough water to raise the sea level by 24 ft (7.4 m).

The paper, published December 10, 2019, in *Nature* (*https://www.nature.com/articles/s41586-019-1855-2*), is the result of an international collaboration between 89 polar scientists from 50 scientific institutions supported by NASA and ESA. The Ice Sheet Mass Balance Intercomparison Exercise (IMBIE) used well-calibrated data from 13 NASA and ESA satellite missions to create the most accurate measurements of ice loss to date. The team found that half of the loss is tied to surface ice melting in warmer air. The rest of the loss is the result of factors such as warmer ocean temperatures, iceberg calving, and the ice sheet shedding ice into the ocean more quickly.

"There are climate projections that are based on models of varying levels of complexity and observations, but they have large uncertainties. Our study is purely an observational one that tests those uncertainties. Therefore, we have irrefutable evidence that we seem to be on track with one of the most pessimistic sea level rise scenarios," said **Erik Ivins** [NASA/Jet Propulsion Laboratory], second author of the study.

Greenland is home to the only permanent ice sheet outside Antarctica. The sheet covers three-fourths of Greenland's land mass. But in the last 26 years, Greenland's melting ice has added 0.4 in (11 mm) to sea level rise. Its cumulative 3.8 trillion tons of melted ice is equivalent to adding the water from 120 million Olympic-size swimming pools to the ocean every year, for 26 years.

"As a rule of thumb, for every centimeter rise in global sea level, another 6 million people are exposed to coastal flooding around the planet," said **Andrew Shepherd** [University of Leeds, U.K.], lead study author. "On current trends, Greenland ice melting will cause 100 million people to be flooded each year by the end of the century—so 400 million in total due to sea level rise."

In addition to storm surges and high tides that will increase flooding in many regions, sea level rise exacerbates events like hurricanes. Greenland's shrinking ice sheet also speeds up global warming. The vast expanse of snow and ice helps cool down Earth by reflecting the Sun's rays back into space. As the ice melts and retreats, the region absorbs more solar radiation, which warms the planet.

The new study will contribute to the evaluation and evolution of sea level rise models used by the Intergovernmental Panel on Climate Change in evaluating risks to current and future populations. The results of the study currently appear consistent with the panel's worst-case projections for sea level rise in the next 80 years.

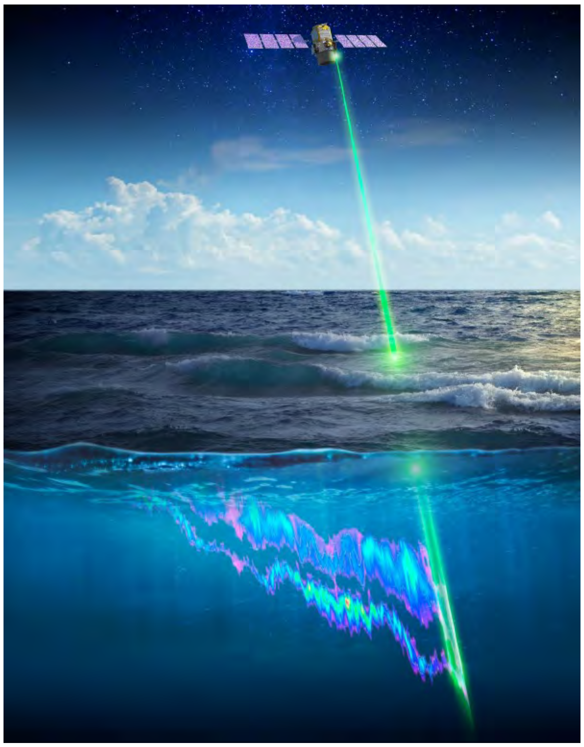
"The full set of consequences of future melt from the Greenland Ice Sheet remain uncertain, but even a small increase in sea level can have devastating effects on ports and coastal zones, cause destructive erosion, wetland flooding, and aquifer and agricultural soil contamination with salt," said Ivins.

This is the third IMBIE study on ice loss as a result of global warming. IMBIE's first report in 2012 measured both Greenland and Antarctica's shrinking ice sheets, finding that the combined ice losses from Antarctica and Greenland had increased over time and that the ice sheets were losing three times as much ice as they were in the early 1990s. Antarctica and Greenland continue to lose ice today, and that rate of loss has accelerated since the first IMBIE study. IMBIE is supported by the NASA Earth Science Division and the ESA Climate Change Initiative. ■

NASA, French Space Laser Measures Massive Migration of Ocean Animals

Steve Cole, NASA Headquarters, stephen.e.cole@nasa.gov
Joe Atkinson, NASA's Langley Research Center, joseph.s.atkinson@nasa.gov

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



Every night, under the cover of darkness, countless small sea creatures—from squid to krill—swim from the ocean depths to near the surface to feed. This vast animal migration—the largest on the planet and a critical part of Earth's climate system—has been observed globally for the first time thanks to an unexpected application of data from a space-based laser.

Researchers observed this vertical migration pattern using the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite—a joint venture between NASA and the French space agency, Centre National d'Études Spatiales (CNES)—that launched in 2006. They published their findings in the journal *Nature* (*https://www.nature.com/articles/s41586-019-1796-9*).

"This is the latest study to demonstrate something that came as a surprise to many: that lidars have the sensitivity to provide scientifically useful ocean measurements from space," said **Chris Hostetler** [NASA's Langley Research Center], a co-author on the study. "I think we are just scratching the surface of exciting new ocean science that can be accomplished with lidar."

The study looks at a phenomenon known as *diel vertical migration* (DVM), in which small sea creatures swim up from the deep ocean at night to feed on phytoplankton near the surface, then return to the depths just before sunrise. Scientists recognize this natural daily movement around the world as the largest migration of animals on Earth in terms of total number.

The cumulative effect of daily vertically migrating creatures on Earth's climate is significant. During the day, ocean phytoplankton photosynthesize and, in the process, absorb significant amounts of carbon dioxide, which contributes to the ocean's ability to absorb the greenhouse gas from the atmosphere. Animals that undergo DVM come up to the surface to feed on phytoplankton near the ocean's surface and then swim back down, taking the phytoplankton carbon with them. Much of this carbon is then defecated at depths where it is effectively trapped deep in the ocean, preventing its release back into the atmosphere.

"What the lidar from space allowed us to do is sample these migrating animals on a global scale every 16 days for 10 years," said **Mike Behrenfeld** [Oregon State University], the lead for the study. "We've never had anywhere near that kind of global coverage to allow us to look at the behavior, distribution, and abundance of these animals."

Zeroing in on tropical and subtropical ocean regions, researchers found that while there are fewer vertically migrating animals in lower-nutrient and clearer waters, they comprise a greater fraction of the total animal population in these regions. This is because the migration is a behavior that has evolved primarily to avoid visual predators during the day when visual predators have their greatest advantage in clear ocean regions.

In murkier and more nutrient-rich regions, the abundance of animals that undergo DMV is higher, but they represent a smaller fraction of the total animal population because visual predators are at a disadvantage. In these regions, many animals just stay near the surface both day and night.

The researchers also observed long-term changes in populations of migrating animals, likely driven by climate variations. During the study period (2008 to 2017), CALIPSO data revealed an increase in migrating

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NASA Earth Science in the News

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

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

Fever Chart: Earth Had Its Hottest Decade on Record in 2010s, January 15, *apnews.com*. The decade that just ended was by far the hottest ever measured on Earth, capped off by the second-warmest year on record, two U.S. agencies reported on January 15, 2020. And scientists said they see no end to the way man-made climate change keeps shattering records. "If you think you've heard this story before, you haven't seen anything yet," **Gavin Schmidt** [NASA's Goddard Institute for Space Studies (GISS)—*Director of GISS*] said at the close of a decade plagued by raging wildfires, melting ice, and extreme weather that researchers have repeatedly tied to human activity. Schmidt said Earth as a whole is probably the hottest it has been during the *Holocene*—the past 11,500 years or so—meaning this could be the warmest period since the dawn of civilization. But scientists' estimates of ancient global temperatures, based on tree rings, ice cores, and other telltale signs, are not precise enough to say that with certainty. The 2010s averaged 58.4 °F (14.7 °C) worldwide, or 1.4 °F (0.8 °C) higher than the twentieth century average and more than one-third of a degree Fahrenheit (one-fifth of a degree Celsius) warmer than the previous decade, which had been the hottest on record, according to the National Oceanic and Atmospheric Administration (NOAA). The decade had 8 of the 10 hottest years on record. The only other years in the top 10 were 2005 and 1998. NASA and NOAA also calculated that 2019 was the second-hottest year in the 140 years of record-keeping. Five other global teams of monitoring scientists agreed, based on temperature readings taken on Earth's surface, while various satellite-based measurements said it was anywhere from the hottest year on record to the third-hottest. Several scientists said the coming years will be even hotter, knocking these years out of the record books. "This is going to be part of what we see every year until we stabilize greenhouse gases" from the burning of coal, oil, and gas, Schmidt said.

In Australia, Rain Falls, but Wildfires Expected to Intensify, NASA Says, January 7, *space.com*. Rain passed over southeastern Australia on January 5, 2020,

Figure 1. This natural-color image was acquired on January 4, 2020, by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite. Smoke has a grayish color, while clouds are bright white. It is likely that some of the white patches above the smoke are *pyrocumulonimbus clouds*—clouds created by the convection and heat rising from a fire. **Image credit:** NASA's Earth Observatory

offering a brief moment of relief from the deadly wildfires that have been raging across the continent for months. NASA's satellites have been tracking the widespread fires from space, watching as smoke and aerosols spread across the states of New South Wales and Victoria. While the rain gave residents in the area a moment to regroup, the fires were expected to quickly regain their strength by January 9, when forecasters predicted hot, dry weather and winds will return, according to a statement from NASA.[1] Forecasters have also warned that haze and smoke in the area remain hazardous after the rainstorm. When the hot winds return, there is also a chance that the fires could grow and merge, creating "megafires" that would further devastate the area, according to the statement. Before the rainfall, satellites captured images of burning fires

[1] To read the report, visit *https://earthobservatory.nasa.gov/images/146110/fires-and-smoke-engulf-southeastern-australia*.

and billowing smoke on January 4—see **Figure 1**. The image shows three distinct plumes of smoke rising from the fires. The Ozone Mapping and Profiler Suite (OMPS) instrument on the Suomi National Polar-orbiting Partnership (NPP) satellite, which is jointly operated by NASA and the National Oceanic and Atmospheric Administration (NOAA), also observed the area and recorded massive amounts of particles within the smoke. The satellite data revealed traces of soot, dust, and aerosols at or above the highest levels that the OMPS instrument can measure, according to the statement. NASA's satellites will continue to track the evolution of the wildfires and spreading smoke as conditions worsen during the heatwave expected later in the week.

***You've Likely Never Heard of the World's Greatest Ocean Migration. Satellite Data Are Helping Scientists Study It,** January 1, *pilotonline.com*. The greatest animal migration on Earth is likely something you never heard of and few have witnessed: legions of tiny marine creatures rising to the ocean surface every night to feed on tiny plants, then sinking back into the deep, dark water at dawn. Called the *diel vertical migration*, it was first recorded nearly 200 years ago by hauling ship nets through the water column. Today, marine scientists still sample the movement using shipboard nets. They also shoot acoustic signals into the water to track the sound backscattering off the zooplankton as they migrate up and down. Some collect data from aircraft, deploying a lidar system that uses a kind of laser radar to create the backscatter. But such methods take time and resources and are limited. A couple years ago, oceanographers working with NASA's Langley Research Center (LaRC) discovered that NASA's Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) orbiting satellite and its lidar instrument—built to study clouds, not oceans—have been collecting data on this migration on a global scale since 2006. Scientists were astonished—and delighted. "The lidar has given us our first measurements of animals—in fact, animal behavior—from space," said biological oceanographer **Michael Behrenfeld** [Oregon State University]. "What (it) has allowed us to do for the first time is actually to study this migration on a global scale every 16 days for 10 years. And that's a very powerful place to be." Behrenfeld is lead author of a paper on this research that recently published in the science journal *Nature*.[2] Behrenfeld has collaborated for years with atmospheric scientist **Yongxiang Hu** [LaRC], on ways to use NASA's current assets in space to collect ocean data.

Map Reveals Land Beneath Antarctic Ice Sheet in Unprecedented Detail, December 12, *upi.com*. Scientists have successfully mapped the topography of the land beneath Antarctica's ice sheet at high resolution by combining radar observations with ice-volume and flow-velocity data. The new map will help scientists identify regions of ice that are likely to be more or less susceptible to the deleterious effects of climate change—see **Figure 2**. The results of the BedMachine

[2] To read the *Nature* paper, visit *https://www.nature.com/articles/s41586-019-1796-9*. The study was also reported on NASA's Earth Observatory website at *https://earthobservatory.nasa.gov/images/145941/satellite-observes-massive-ocean-migration*.

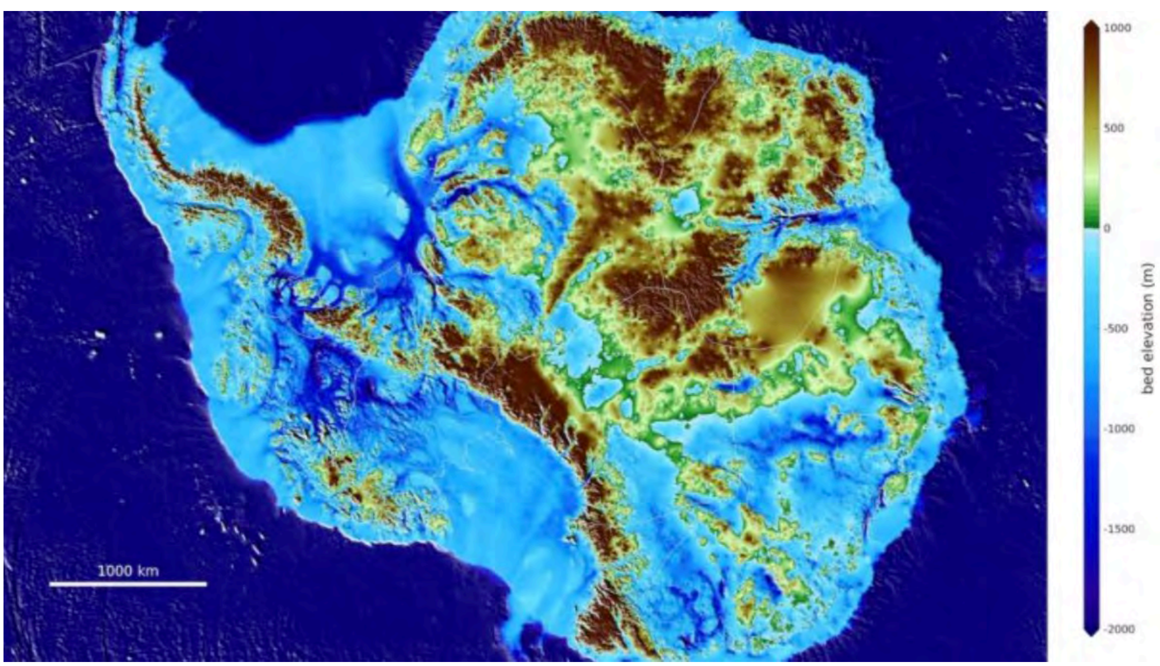

Figure 2. The new Antarctic bed topography product was constructed using ice-thickness data from 19 different research institutes dating back to 1967, encompassing nearly a million line-miles of radar soundings. In addition, BedMachine's creators utilized ice shelf bathymetry measurements from NASA's Operation IceBridge campaigns, as well as seismic information, where available. **Image credit:** University of California, Irvine.

project (*https://nsidc.org/data/nsidc-0756*), published this week in the journal *Nature Geoscience*,[3] revealed a variety of interesting topographical features. Scientists found ridges that stabilize ice flowing across the Transantarctic Mountains, as well as structural features conducive to accelerated melting beneath the Thwaites and Pine Island glaciers in Western Antarctica. To build the new map, scientists used data from a wide diversity of sources, including observations from 19 surveys of Antarctic ice thickness. The mapping model utilized ice flow velocity and seismic data, as well as topography measurements made by NASA's Operation IceBridge surveys. "Using BedMachine to zoom into particular sectors of Antarctica, you find essential details such as bumps and hollows beneath the ice that may accelerate, slow down, or even stop the retreat of glaciers," stated **Mathieu Morlighem** [University of California, Irvine]. The project revealed a surprisingly deep bed beneath Antarctica's Recovery and Support Force glaciers, which could accelerate their retreat. The new map also revealed the world's deepest land canyon underneath East Antarctica's Denman Glacier.

[3] To read the study, visit *https://www.nature.com/articles/s41561-019-0510-8*.

*See News Story in this issue.

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

NASA, French Space Laser Measures Massive Migration of Ocean Animals

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animal biomass in the subtropical waters of the North and South Pacific, North Atlantic, and South Indian oceans. In the tropical regions and North Atlantic, biomass decreased. In all but the tropical Atlantic regions, these changes correlated with changes in phytoplankton production.

This animal-mediated carbon conveyor belt is recognized as an important mechanism in Earth's carbon cycle. Scientists are adding animals that undergo DVM as a key element in climate models.

"What these modelers haven't had is a global dataset to calibrate these models with, to tell them where these migrators are most important, where they're most abundant, and how they change over time," said Behrenfeld. "The new satellite data give us an opportunity to combine satellite observations with the models and do a better job quantifying the impact of this enormous animal migration on Earth's carbon cycle."

The satellite data are also relevant to global fisheries because the migrating animals are an important food source for larger predators that lurk in the depths of the ocean. Those predators are often species of fish that are attractive to commercial fisheries. The larger the DVM signal, the larger the population of fish that can live in the deep sea.

Though CALIPSO's laser was designed to measure clouds and atmospheric aerosols, it can penetrate the upper 20 m (65 ft) of the ocean's surface layer. If the migrating animals reach this layer, they are detected by CALIPSO.

Earth Science Meeting and Workshop Calendar

NASA Community

February 19–20, 2020
TROPICS Applications Workshop
Miami, FL
https://tropics.ccs.miami.edu

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

Global Science Community

April 25–26, 2020
USA Science and Engineering Festival,
Washington, DC
https://usasciencefestival.org/2020-expo

May 3–8, 2020
EGU General Assembly 2020, Vienna, Austria
https://www.egu2020.eu

May 24–28, 2020
JpGU-AGU Joint Meeting, Chiba, Japan
http://www.jpgu.org/meeting_e2020

June 24–July 4, 2020
Asia Oceania Geosciences Society,
Hongcheon, South Korea
http://www.asiaoceania.org/aogs2020/public.asp?page=home.html

July 19–24, 2020
IGARSS 2020, Waikoloa, Hawaii
https://igarss2020.org

August 15–22, 2020
43rd Scientific Assembly of the Committee
on Space Research and Associated Events
COSPAR 2020, Sydney, Australia
https://www.cospar2020.org/index.php

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

AGU	American Geophysical Union
CNES	Centre National d'Études Spatiale [French Space Agency]
DSCOVR	Deep Space Climate Observatory
ECOSTRESS	Ecosystem Spaceborne Thermal Radiometer Experiment on Space Station
EOSDIS	Earth Observing System Data and Information System
ESA	European Space Agency
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
GSFC	NASA's Goddard Space Flight Center
ICESat	Ice, Clouds, and Land Elevation Satellite
ISS	International Space Station
LANCE	Land, Atmosphere Near real-time Capability for the Earth Observing System
LP DAAC	Land Processes Distributed Active Archive Center
NOAA	National Oceanic and Atmospheric Administration
OCO-3	Orbiting Carbon Experiment–3
TOPEX	Ocean Topography Experiment
USDA	United States Department of Agriculture

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The Earth Observer

The Earth Observer is published by the Science Communication Support Office, Code 610, NASA's Goddard Space Flight Center, Greenbelt, Maryland 20771, telephone (301) 614-5561, FAX (301) 614-6530, and is available in color at *eospso.nasa.gov/earth-observer-archive*.

Articles, contributions to the meeting calendar, and suggestions are welcomed. Contributions to the calendars should contain location, person to contact, telephone number, and e-mail address. Newsletter content is due on the weekday closest to the 1st of the month preceding the publication—e.g., December 1 for the January–February issue; February 1 for March–April, and so on.

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The Earth Observer Staff

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

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NP-2020-2-517-GSFC