Thirty Years Reporting on NASA's Earth Science Program

The Earth Observer

National Aeronautics and Space Administration

January – February 2019. Volume 31, Issue 1

Editor's Corner

Steve Platnick
EOS Senior Project Scientist

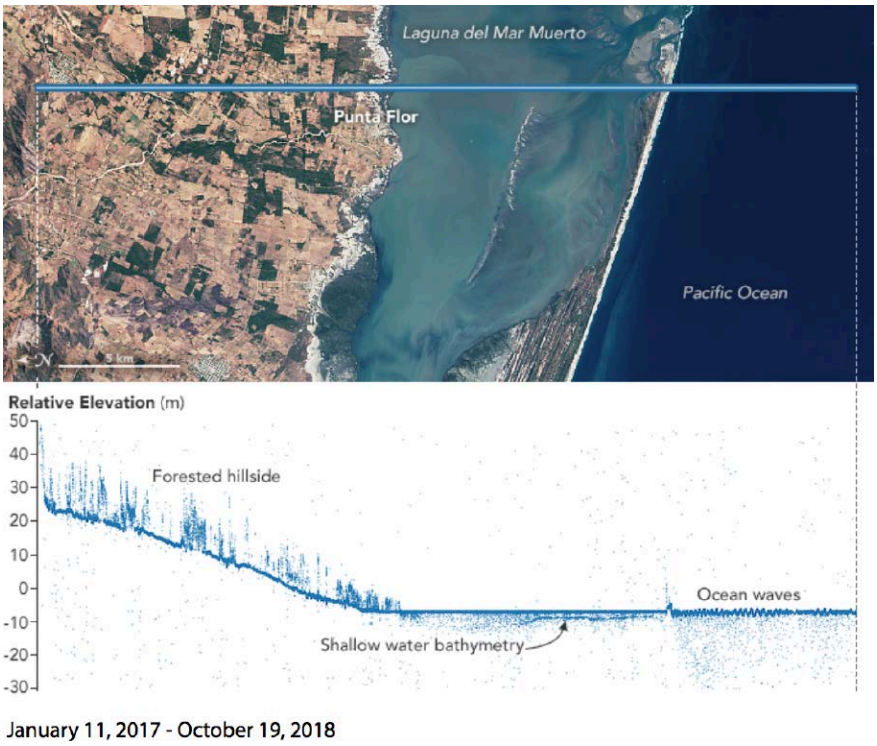
The new year got off to a challenging start for many of us when much of the U.S. Government—including NASA—shut down from December 23, 2018 to January 25, 2019. Fortunately, *The Earth Observer* contractor staff was able to continue working. While the specific plans for this issue had to be tweaked and the production schedule inevitably slipped, the publication before you is a testament to the resiliency of the team. For hardcopy subscribers to the newsletter, the previous issue of the newsletter (November–December 2018) likely only recently found its way to your mailbox due to furlough-induced printing delays.

The previous issue of *The Earth Observer* included a status update on the Ice, Cloud, and land Elevation Satellite–2 (ICESat-2) that included an image of ATLAS (lidar) returns during an Antarctica overpass.[1] But as its name implies, the mission's capabilities extend beyond studying the cryosphere. As ICESat-2 orbits over forests, it can distinguish not only the tops of trees but also the inner canopies and the forest floor—see **Figure**. While the science team was unsure how clear the terrain would be under dense canopies like those found in tropical rainforests, the data turned out even better than expected. By measuring tree heights globally, the ICESat-2 mission will be able to improve estimates of how much carbon is stored in forests.

There is also personnel news to report for ICESat-2. **Tom Neumann** [GSFC] has been named ICESat-2 Project Scientist, replacing **Thorsten Markus** [GSFC] who served in that role for the past decade. Neumann, who had previously been ICESat-2's Deputy Project Scientist, became the mission's Project Scientist after the satellite was commissioned. He has been at NASA since 2008, and was previously an assistant professor at the University of Vermont, Burlington. Neumann has conducted field work on the Greenland and Antarctic ice sheets—leading four expeditions and participating in an additional five. **Nathan Kurtz** [GSFC] has been named the new ICESat-2 Deputy Project

[1] This and several other items mentioned in this Editorial were discussed in the Editorial of the November–December 2018 issue of *The Earth Observer* [**Volume 30**, **Issue 6**, pp. 1-3].

continued on page 2



NASA's Ice, Cloud and land Elevation Satellite-2 (ICESat-2) not only provides new data to scientists on Earth's polar ice, it also collects detailed elevation measurements over tropical and temperate latitudes, providing a remarkable look at the heights of land and ocean features.

A forested hillside in Mexico is visible in the elevation measurement [graph, *below*], acquired on October 19, 2018, by the Advanced Topographic Laser Altimeter System (ATLAS) on ICESat-2. For reference, the orbital path is laid over a natural-color image acquired on January 11, 2017, by the Operational Land Imager (OLI) on Landsat 8. Each dot on the visualization represents a photon detected by ATLAS. Most of the dots in this *photon cloud* are clustered around a surface, whether it be a tree top, the ground, or waves in the ocean. Following this orbital path from north to south [*left to right*] reveals a vegetated hillside sloping down toward the coastline. ICESat-2 can distinguish not only the tops of trees but also the inner canopies and the forest floor. As the path continues past the coastline, photons returned from the seafloor become visible. Bathymetry measurements like this are possible in clear coastal areas—sometimes as deep as 80 ft (25 m). Finally, as the path moves beyond Laguna del Mar Muerto and over the Pacific Ocean, the surface of the water is visibly rougher and the photons trace the height of individual waves.

Image and text credit: NASA's Earth Observatory

editor's corner

In This Issue

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Scientist. Congratulations and best wishes to Neumann and Kurtz in their new roles and well-deserved thanks to Markus for helping to guide the ICESat-2 mission during his tenure.

The last issue reported on the successful launch of GEDI on December 5, 2018, and the subsequent installation of the instrument on the Japanese Experiment Module-Exposed Facility on the International Space Station on December 13. Commissioning began on January 2, 2019 and should be completed by the end of March. As of this writing, all GEDI subsystems are powered up, except the pointing control mechanism (which begins testing soon). All eight laser beams are returning waveforms. Laser pulses are consistent with pre-launch performance, and noise performance is good in all channels. Laser boresight alignment for all three lasers are good and well within field of view. Once out of the commissioning phase, GEDI will begin collecting planned science data. These early data will be used to refine science calibration efforts leading to operational production of GEDI data products.

Meanwhile, ECOSTRESS has resumed nominal operations after addressing an issue with one of its mass storage units that required switching to a redundant system (reported in the last issue). Acquisition times and revisit frequencies vary with the ISS orbit, with an average revisit over the U.S. of approximately four days. ECOSTRESS provides the opportunity to evaluate the way plants respond to heat and water stress at resolutions better than currently available sensors. ECOSTRESS data are available through the early adopter program.[2]

[2] Learn more about the ECOSTRESS Early Adopter Program at *https://ecostress.jpl.nasa.gov/applications*.

In the last issue, we reported that the GRACE–FO mission successfully completed a switchover to a backup system after an anomaly in the primary Microwave Instrument (MWI) on one of the mission's twin spacecraft necessitated the change. Once that switchover was complete, in later October, GRACE-FO resumed in-orbit checks, which included calibrations and other system tests. The GRACE-FO team has been collecting science data since the October switchover, and transitioned into the nominal science data acquisition mission phase at the end of January 2019. The team is currently doing a detailed verification and validation of the collected science data and is preparing to release the first batch in late spring 2019.

The first joint GRACE and GRACE-FO Science Team Meeting (GSTM) took place October 9-11, 2018, at GFZ, in Potsdam, Germany. The STM was an opportunity to showcase novel science applications of GRACE data. There was a particular focus on the utility of combining gravity data with data from other sensors to achieve improvements in resolving geophysical signals on improved temporal and spatial scales. These new products have already shown great potential for science and applications use, providing scientists and decision makers a new perspective on water resources. With this being the first gathering of the science team since the GRACE-FO launch in May 2018, the meeting was also an opportunity to show how these new research areas are continuing to expand. Turn to page 17 to read a summary of this meeting.

Additionally, the joint MODIS–VIIRS Science Team Meeting (STM) took place October 15-18, 2018, in Silver Spring, MD. Plenary sessions focused on overall product status (data continuity between the sensors in particular) and science investigations across the

Atmosphere, Land, and Ocean science disciplines. Each discipline had separate breakouts to discuss issues of specific interest. At the end of the STM, a Calibration Workshop was held to review the operation and measurement performance of each instrument. This science team is part of a broader effort within NASA's Earth Science Division to establish product and science continuity between EOS-era and Suomi NPP/JPSS-era observations. To read summaries of both the MODIS–VIIRS STM and the Calibration Workshop, turn to page 7 of this issue.

To close out 2018, NASA's Science Communications Support Office (SCSO) supported the NASA Science exhibit at the AGU's Fall Meeting, held December 10-14, 2018, in Washington, DC. The booth featured NASA's Hyperwall, a virtual reality space, a hands-on demonstration area, and a NASA Anniversaries area to celebrate the sixtieth anniversary of the agency. New this year, NASA partnered with AGU to successfully recruit 70 NASA scientists to participate in the AGU Centennial Narratives Project. To learn more about the exhibit and NASA's participation in the AGU Centennial Narratives Project, turn to page 4 of this issue.

Last, but certainly not least, the GPM mission is celebrating its fifth anniversary on February 27, 2019. It has provided unprecedented three-dimensional views of precipitation, from light rain to intense thunderstorms. Building on the 17-year success of the NASA–JAXA TRMM mission, the GPM Core Observatory (GPM-CO) is the first NASA satellite mission specifically designed with sensors to observe the structure and intensities of light to heavy rain and falling snow. GPM-CO includes the NASA-provided GPM Microwave Imager (GMI) and the JAXA-provided Dual-frequency Precipitation Radar (DPR). These sensors were devised as reference standards to unify precipitation measurements from partner satellite data and provide high-quality active and passive microwave observations across all times of day. These intercalibrated partner satellite retrievals are used in combination with infrared data to produce high temporal and spatial resolution of rainfall estimates every 30 minutes at 0.1º (10 km) resolution globally.

The GPM-CO mission is in extended operations with all instruments working nominally and with fuel to continue operations potentially into the early to mid-2030's. Many advances have been made with GPM data over the past five years, including improving sensor calibration, assimilation of GPM into global modeling and analysis systems, extension of latent heating products to middle/high latitudes, retrieval algorithms, and increasing understanding of the characteristics of liquid and frozen precipitation. Visit GPM on Twitter at *@NASARain* to learn more about GPM's anniversary and see other highlights from its five years of service.

I congratulate the entire GPM Team—past and present—for the success of the mission to date, and look forward to many more years of pioneering precipitation science. ■

Undefined Acronyms Used in Editorial and Table of Contents

AGU	American Geophysical Union
ATLAS	Advanced Topographic Laser Altimeter System
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
EOS	Earth Observing System
GEDI	Global Ecosystem Dynamics Investigation
GFZ	Geoforschungszentrum [German Research Center for Geosciences]
GPM	Global Precipitation Measurement
GRACE	Gravity Recovery and Climate Experiment
GRACE-FO	Gravity Recovery and Climate Experiment Follow-On
GSFC	NASA's Goddard Space Flight Center
JAXA	Japan Aerospace Exploration Agency
JPSS	Joint Polar Satellite System
MODIS	Moderate Resolution Imaging Spectroradiometer
NOAA	National Oceanic and Atmospheric Administration
Suomi NPP	Suomi National Polar-orbiting Partnership
TRMM	Tropical Rainfall Measuring Mission
VIIRS	Visible Infrared Imaging Radiometer Suite

feature article

NASA's Outreach Activities at the 2018 AGU Fall Meeting in Our Nation's Capital

Heather Hanson, NASA's Goddard Space Flight Center/Global Science and Technology, Inc., heather.h.hanson@nasa.gov

Introduction

To close out 2018, NASA's Science Communications Support Office (SCSO)[1] supported the largest Earth and space science meeting in the world—the American Geophysical Union (AGU) Fall Meeting, held December 10-14, 2018. For nearly 50 years, the AGU Fall Meeting has been held at the Moscone Center in San Francisco, CA; however, due to the Center's renovation activities, AGU chose an alternative meeting location for both 2017 and 2018.[2] So, the 2018 Fall Meeting was held in Washington, DC.[3] To view photos from AGU and other events supported by NASA's SCSO, visit *https://www.flickr.com/photos/eospso/albums*.

Prior to the AGU Fall meeting, the SCSO organized the 2018 Annual Science Mission Directorate (SMD) Communications Meeting, where NASA employees and contractors who contribute to the agency's communications activities convened to shape outreach communications strategies and guide the workflow for the coming year—see the section, *Annual SMD Communications Meeting,* on page 6.

New this year, NASA partnered with AGU to successfully recruit 70 NASA scientists to participate in the AGU Centennial Narratives Project—see the text box, *NASA Participates in AGU Centennial Narratives Project*, on page 6.

AGU Fall Meeting

As has been the case for more than 11 years, SCSO staff organized and supported the NASA exhibit at the AGU Fall Meeting—the SCSO's biggest event of the year in terms of event support. With help from the NASA outreach community, the 70- x 50-ft (21- x 15-m) booth space—the largest NASA exhibit at AGU ever—represented the depth and breadth of NASA's science activities across SMD's four disciplines: Earth Science, Planetary Science, Heliophysics, and Astrophysics. The booth featured NASA's Hyperwall,[4] a virtual reality space, a hands-on demonstration area, and a NASA Anniversaries area to celebrate the sixtieth anniversary of the agency. Given this year's new meeting location, a large NASA Science monument—inspired by the Washington Monument—was at the heart of the exhibit—see **Photo 1**—with Washington-inspired

[1] The SCSO 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] The AGU diaspora gathered in New Orleans in 2017. See "NASA's Outreach Activities at AGU" in the January–February 2018 issue of *The Earth Observer* [**Volume 30**, **Issue 1**, pp. 5-8—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Jan_Feb_2018_color508_0.pdf#page=5*].

[3] AGU's Centennial is taking place in 2019; plans call for a return to San Francisco, CA to celebrate in the expanded and improved Moscone Center, December 9-13, 2019.

[4] NASA's Hyperwall is a video wall capable of displaying multiple high-definition data visualizations and/or images simultaneously across an arrangement of screens.

Photo 1. Hyperwall presenters attracted large crowds to the NASA exhibit by telling their science stories and showing dynamic visualizations. NASA's Science monument, located at the center of the NASA exhibit, can be seen near the center of this photo. **Photo credit:** NASA

street signs to help visitors navigate the exhibit. A total of 105 *science stories* (15 minutes each) and *flash talks* (7 minutes each) were offered in front of the Hyperwall, as well as 32 hands-on or virtual-reality experiences in the demonstration areas. To view the full schedule of events at the booth, visit *https://eospso.gsfc.nasa.gov/sites/default/files/publications/AGU_2018_Events_Program.pdf*.

NASA Administrator **Jim Bridenstine** and **Thomas Zurbuchen** [NASA Headquarters—*Associate Administrator of SMD*] visited the exhibit on Tuesday, December 11—see **Photos 2-3**. The two toured the exhibit and talked with several NASA booth participants before making their way to the Hyperwall stage to say a few words and introduce the winners of the *2018 AGU Data Visualization and Storytelling Competition*—a contest (funded by a grant from NASA) 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.

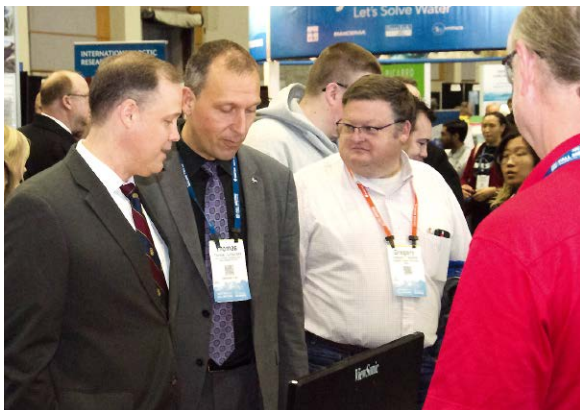

Photo 2. NASA Administrator **Jim Bridenstine** [*left*] and **Thomas Zurbuchen** [*center*] stopped at several of the activities during their tour of the NASA exhibit. **Photo credit:** NASA

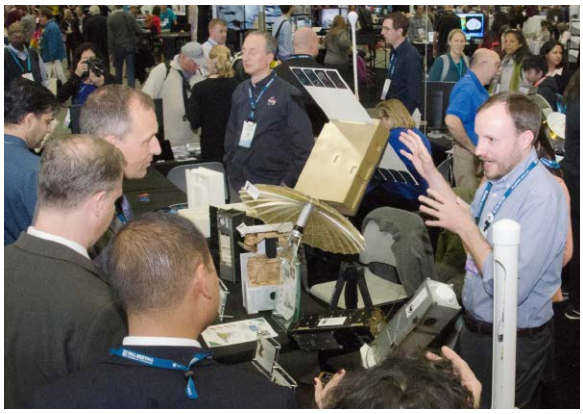

Photo 3. Philip Larkin [NASA's Goddard Space Flight Center (GSFC)] from NASA's Earth Science Technology Office talked with NASA Administrator **Jim Bridenstine** and **Thomas Zurbuchen** about NASA's latest technology discoveries. **Photo credit:** NASA

Presentations and demonstrations continuously attracted large crowds and generated lots of questions and healthy discussions among attendees. Several information tables where attendees could collect resources and talk one-on-one with NASA personnel about specific topics also received a steady stream of visitors—see **Photos 4-5**. As always, the 2019 NASA Science Calendar was one of the many resources that attracted attendees to the NASA booth—see **Photo 6**. To view the calendar online, visit *https://eospso.gsfc.nasa.gov/sites/default/files/publications/2019%20NASA%20Science%20Calendar_final_508.pdf*.

Photo 4. Attendees visiting the Landsat table learned from **Allison Nussbaum** [GSFC—*Intern*] about the long heritage of the mission and what the satellite program has allowed us to discover over the more than 40 years of the Landsat Program. **Photo credit:** NASA

Photo 5. At the virtual-reality area attendees had an opportunity to visualize NASA Science data using virtual-reality goggles. **Photo credit:** NASA

Photo 6. Attendees waited patiently to obtain a coveted copy of the 2019 NASA Science calendar. **Photo credit:** NASA

feature article

In addition to the calendar, the exhibit offered a wide range of printed materials—mission brochures, story booklets, fact sheets, and lithographs—that represent NASA's Earth Science, Planetary Science, Heliophysics, and Astrophysics activities.

New this year, the exhibit featured a hands-on activity to celebrate NASA's sixtieth anniversary called *Stepping through Moments in NASA History*. To participate, attendees were asked to take one of 5 quizzes, each with 12 questions based on the Agency's sixtieth anniversary as well as the first Apollo moon landing's fiftieth anniversary—see **Photo 7**. A small prize was given to individuals who got seven or more correct answers. The intent of this activity was to engage individuals and jog memories of NASA from 60 years ago to today.

Photo 7. NASA's *Stepping Through Moments in NASA History* activity promoted attendees to recall NASA events from the past 60 years. **Photo credit:** NASA

NASA Participates in AGU Centennial Narratives Project

The year 2019 marks AGU's Centennial year, a milestone representing the innovations, discoveries, connections, and solutions in Earth and space science over the past century, and the progress to come.

The AGU Centennial Narratives Project is an opportunity for individuals to share their personal Earth and space science stories. To support this effort, NASA successfully recruited 70 NASA scientists to participate in the project. During the AGU Fall Meeting, a team from StoryCorps* recorded longer-form interviews with the NASA participants. NASA was honored to be part of such a tremendous effort to amplify the accomplishments of science over the last 100 years.

A library of all AGU narratives will be continually updated as content is uploaded at *https://centennial.agu.org/earth-space-science-history/agu-narratives-library*.

* StoryCorps is an organization with a mission to preserve and share humanity's stories in order to build connections between people and create a more just and compassionate world. See *https://storycorps.org/about* to learn more.

Annual SMD Communications Meeting

The 2018 Annual SMD Communications Meeting was held at the Gaylord National Resort and Convention Center (located just outside Washington, DC) on Sunday, December 9. More than 180 NASA employees and contractors attended the daylong event. This annual meeting is an opportunity for those involved in NASA's communications activities, who are gathering to participate in AGU, to have a face-to-face meeting to shape outreach communications strategies and guide work flow for the coming year.

Kristen Erickson [NASA Headquarters (HQ)—*Director of Science Engagement and Partnerships*] provided opening remarks and a welcome message and introduced **Thomas Zurbuchen**, who shared his vision of the state of SMD and the agency's communication strategies. Next, the five SMD division heads—**Michael Freilich** [NASA HQ—*Director of the Earth Science Division*], **Nicola Fox** [NASA HQ—*Director of the Heliophysics Science Division*], **Lori Glaze** [NASA HQ—*Acting Director of the Planetary Science Division*], **Paul Hertz** [NASA HQ—*Director of the Astrophysics Science Division*], and **John Lee** [NASA HQ—*Director of the Joint Agency Satellite Division*]—spoke about the state of their respective SMD programs. In addition, **Dwayne Brown** [NASA HQ—*Senior Communications Official*] and **Emily Furfaro** [NASA HQ—*Social Media Specialist*] spoke about the agency's communications and social media efforts as well as future plans. In the afternoon, there were breakout sessions for the Astrophysics, Heliophysics, Earth Science, and Planetary Science Division's activities, where participants discussed story ideas and toolkit topics.

Conclusion

The SCSO plans to represent NASA at a variety of scientific venues and public events in the coming year, including the 2019 AGU upon its return to San Francisco, CA. Outreach exhibits allow the agency to represent its science activities in a single setting, often reaching thousands of people in a very short time. Currently, the Hyperwall and Dynamic Planet[5] provide exciting tools for NASA to communicate its science activities on a one-on-one basis.

Looking ahead, the SCSO remains committed to developing and implementing the next-generation communication platforms. To see where we're headed next, follow the SCSO on Twitter using @NASAHyperwall. We encourage you to stop by our displays at future venues. ■

[5] NASA's Dynamic Planet is a 48-inch spherical display system that provides a unique and vibrant global perspective of Earth, our Sun, various planetary bodies in our solar system, and the Universe, to increase and improve scientific understanding.

The Continuity Quest Continues: Summary of the 2018 MODIS–VIIRS Science Team Meeting

Alan Ward, NASA's Goddard Space Flight Center/Global Science and Technology, Inc., alan.b.ward@nasa.gov
Heather Hanson, NASA's Goddard Space Flight Center/Global Science and Technology, Inc., heather.h.hanson@nasa.gov

Introduction

The Moderate Resolution Imaging Spectroradiometer (MODIS)–Visible Infrared Imaging Radiometer Suite (VIIRS) Science Team Meeting (STM) took place October 15-18, 2018, in Silver Spring, MD. Previous meetings of this combined imager group took place in May 2015[1] and June 2016. The focus of the team is on establishing continuity between NASA's Earth Observing System (EOS)-era MODIS products and those from VIIRS onboard the Suomi National Polar-orbiting Partnership (Suomi NPP)[2] and National Oceanic and Atmospheric Administration's (NOAA) Joint Polar-orbiting Satellite System (JPSS)-era platforms, as well as on related science.

In the four years since May 2015, much progress has been made toward this goal. MODIS is now firmly established as a high-quality science instrument with nearly two decades of continuous observations—and over thirty years of observations between Terra and Aqua, combined. Meanwhile, NASA has funded algorithm development for VIIRS (so far, for Suomi NPP only). Extensive validation efforts in the seven years since the Suomi NPP launch have shown that—despite not being specifically designed for climate science—VIIRS *can* be a worthy successor to MODIS. However, more work is needed in order for VIIRS to fulfill its full potential as heir to MODIS—the "EOS workhorse." To obtain the multidecadal time series of key environmental parameters required for climate observations, scientists on both teams have undertaken an effort to transition from products obtained by MODIS to similar products from VIIRS, wherever such comparisons are possible despite some spectral differences of the sensors. Even for two science-quality instruments such as MODIS and VIIRS, these kinds of transitions present challenges: It is never as simple as one-to-one mapping.

Probably the issue that has presented the greatest overall challenge when transitioning from MODIS to VIIRS is that VIIRS was originally designed to serve the needs of operational agencies (the National Weather Service and Department of Defense) whereas MODIS was designed to meet the needs of a global Earth and climate science/research agency (NASA). Thus, unlike MODIS, there were no formal data product continuity requirements that VIIRS was required to meet, which means it is not always easy—or even possible—to map an algorithm or data product for MODIS directly to its "equivalent" on VIIRS. This has resulted in a situation where certain EOS continuity data products cannot be produced from VIIRS for several reasons, including the lack of spectral capability from VIIRS to MODIS. In addition, this has led to several *orphaned products*, where either a proposal was not received by the agency for a given data product, or the principal investigator (PI) of an existing MODIS product or algorithm had a proposal that did not review well enough to receive funding to continue that product for Suomi NPP. This topic, as well as other challenges to MODIS–VIIRS data product continuity, were frequent topics of conversation at the meeting.

The three-and-a-half-day meeting agenda included programmatic updates from representatives of NASA Headquarters (HQ) on the overall Earth Science Program, and then on MODIS and VIIRS specifically; reports on the status of the MODIS and VIIRS

[1] The last meeting reported in *The Earth Observer* was for the 2015 meeting, see "Continuity Assured: The First Postlaunch MODIS/VIIRS Science Team Meeting Summary" in the September–October 2015 issue [**Volume 27**, **Issue 5**, pp. 12-18, 39—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/Sep_Oct_2015_color_508.pdf#page=12*].

[2] Suomi NPP, launched in 2011, was developed as a bridge mission between EOS and JPSS.

Pictured here are several members of the current MODIS–VIIRS Science Team (ST) who were also members or associates of the original MODIS ST, which first met in 1989. They include [*left to right*] **Chris Justice**, **Steve Running**, **Jan–Peter Muller**, **Michael King** [current MODIS ST Leader], **Vince Salomonson** [former MODIS ST Leader], **Bob Murphy** [former MODIS Project Scientist], and **Bruce Guenther** [former MODIS Calibration Support Team Leader]. All these individuals have been instrumental in the long-term success of MODIS on Terra and Aqua. **Photo credit:** Alan Ward

instruments and their respective data products; and several sessions that were used to review algorithm development and science investigations in the Atmosphere, Land, and Ocean Disciplines. There were also opportunities for discipline-specific discussion for Atmosphere and Land,[3] including how to overcome remaining challenges in transitioning from MODIS to VIIRS.

After the STM ended, there was a MODIS Calibration Workshop held on the afternoon of October 18 and a VIIRS Calibration Workshop held the morning of October 19, which focused on the operation and measurement performance of each instrument. To learn more, see *Summary of the MODIS–VIIRS Calibration Workshop*, below.

[3] Note that, for reasons that are explained in the introduction to the *Ocean* session on page 14, the Ocean Discipline chose not to have a separate Breakout Session at this meeting.

The agenda for the week (i.e., the STM and calibration workshops), presentations, and posters can be accessed online at *https://modis.gsfc.nasa.gov/sci_team/meetings/201810*. In addition, a more detailed "white paper" summary of this meeting is posted at *https://modis.gsfc.nasa.gov/sci_team/meetings/201810/MODIS-VIIRS_STM_white_paper_final.pdf*, and is referred to throughout this article.

Day One

The first day featured an Opening Plenary Session in the morning, followed by a session on data products for MODIS and VIIRS early in the afternoon. Later in the afternoon, the focus narrowed to presentations and discussions for the Atmosphere Discipline, with emphasis on science analysis and results.

Summary of the MODIS–VIIRS Calibration Workshop

As a supplement to the MODIS–VIIRS STM, a Calibration Workshop was held in the afternoon of October 18 and the morning of October 19, focusing specifically on the calibration and characterization of the Terra and Aqua MODIS and the Suomi NPP and NOAA-20 VIIRS instruments, respectively. **Jack Xiong** and **Jim Butler** [both from GSFC] chaired the workshop, which included presentations from both the MODIS and VIIRS Characterization Support Teams (MCST/VCST) and from Atmosphere, Land, and Ocean Discipline representatives to the MODIS–VIIRS STM.

The first half-day session focused on the MODIS instruments, with presentations given by members of the MCST. These presentations outlined recent MODIS instrument performance and illustrated detailed results based on various on-orbit calibration activities. In addition, team members presented results from their investigations into improvements to calibration algorithms and mitigation of on-orbit issues. The MCST continues to calibrate and correct for the effects of aging instruments (almost 19 [in Oct 2018] and over 16 years for Terra and Aqua MODIS, respectively). The MODIS reflective solar band (RSB) gain performance has been relatively stable since the last STM in 2016. Recent improvements to the calibration include updating Aqua MODIS bands 1-4 response versus scan angle (RVS) using the response trending from both the on-board calibrators and the pseudo-invariant desert sites over a wide range of scan angles. The thermal emissive bands (TEB) have also shown excellent performance in recent years. Considerable effort was made to update the calibration of several longwave infrared (IR) bands that suffered from electronic crosstalk contamination from neighboring detectors, which affected Terra MODIS bands 27-30. The correction led to a new collection of data products, termed Collection 6.1.

The second half-day session focused on the VIIRS instruments, with presentations given by members of the VCST. Performance updates for and calibration insights into both Suomi NPP and NOAA-20 VIIRS were presented. With a few exceptions, the overall VIIRS instrument performance is more stable than MODIS.

Throughout the calibration workshop, several Science Team members presented their findings as they relate to the calibration efforts regarding these instruments. Two of the presentations covered various lunar calibration topics. Findings from presentations on cross-calibration between MODIS and VIIRS instruments demonstrated the effort needed to enable their calibration consistency. Also reported at the workshop was a brief overview of the performance of the VIIRS instrument for JPSS-2 (scheduled to launch in 2022), based on its prelaunch calibration and characterization. The direct interaction between science team members and the characterization support teams allowed multiple focus areas to be identified and discussed for improving MODIS and VIIRS science data products.

To see the full workshop agenda and download presentations, visit *https://modis.gsfc.nasa.gov/sci_team/meetings/201810/calibration.php*.

Opening Session

Michael King [University of Colorado—*MODIS Science Team Lead*] opened the meeting by welcoming the participants and reviewing the agenda.

Sandra Cauffman [NASA Headquarters (HQ)—*Deputy Director of the Earth Science Division (ESD)*] gave an opening presentation that helped place the activities of MODIS and VIIRS in the broader context of NASA's Earth Science Program. She provided an overview of the program, including an update on the status of ESD FY18 and FY19 appropriations. She noted that funding is substantial and is expected to remain at a high level for FY19 and beyond. Cauffman briefly discussed NASA Earth Science missions planned through 2023, and mentioned recent and upcoming flight program events, and Earth Venture selections.

Cauffman then provided an overview of NASA's Earth Observations from Private Sector Small Constellation Satellite Data Product Pilot project. She explained that NASA has entered into contracts with three private companies (Planet, DigitalGlobe, and Spire) to buy existing data products related to *essential climate variables* (ECVs),[4] derived from private-sector-funded small-satellite constellations. NASA researchers will determine the value of these products for advancing NASA research and applications objectives and activities. She added that NASA has identified a broad set of ESD-funded researchers who will assess the potential of the purchased information to advance NASA research and applications objectives. Cauffman also spoke about the importance of NASA's Earth Science partnerships, which currently include Google, Mercy Corps, Microsoft, and Conservation International. These partnerships allow NASA to amplify our work to understand the Earth as an integrated system and enable societal benefit. In closing, Cauffman provided a snapshot of the 2017 Earth Science Decadal Survey,[5] noting that the report identifies the key questions and challenges for Earth System Science, provides emphasis on competition as a cost-control method, explicitly allows implementation flexibility, explicitly encourages international partnerships, and endorses existing balances in the ESD portfolio.

Following up on Cauffman's opening overview, **Paula Bontempi** [NASA HQ—*MODIS* and *Suomi NPP Program Scientist*] discussed the NASA HQ perspective on MODIS and Suomi NPP. She provided an overview of the proposals received for the 2017 Earth Science Senior Review[6] on MODIS data maintenance for both Terra and Aqua (henceforth referred to as MODIS Maintenance). There were 21 proposals received for Terra and 26 received for Aqua.

Bontempi then discussed the details of the most recent Terra/Aqua/Suomi-NPP ROSES (TASNPP) call.[7] She showed a list of the EOS standard land data products recommended for Suomi NPP, ocean products for Suomi NPP, atmosphere data products recommended for Suomi NPP (some of which come from MODIS, and others from the Microwave Limb Sounder [MLS] and Ozone Monitoring Instrument [OMI] instruments on Aura), and sounder data products recommended for Suomi NPP.

Bontempi went on to address the issue of orphaned data products (described in the Introduction), distinctions between standard data products and operational data products, and algorithmic refinements (and the requirement to develop suitable documentation for each). She also noted that proposers must address work with NASA's Earth Science Data System Program and Earth Science Data and Information System (ESDIS) Project to develop accurate production and archival sizing estimates based on the nature of their products.

Bontempi cautioned that while algorithm refinements for standard products are important, in order to satisfy NASA program management and better serve the research community, the science team also needs to establish a new set of product documentation for the current standard product suite of MODIS and VIIRS, and maintain that level of documentation going forward. Lastly, Bontempi provided a list of topics for further discussion at this meeting, which became a frequent point of reference in the discussions that followed over the next several days.

Following Bontempi's presentation, the meeting's focus shifted from programmatic overviews to specific issues related to MODIS and VIIRS operations and calibration, with an emphasis on establishing continuity between the two instruments.

Xiaoxiong "Jack" Xiong [NASA's Goddard Space Flight Center (GSFC)] shared status updates on Terra and Aqua MODIS instruments and on the Suomi–NPP and

[4] ECVs derive from Climate Data Records (CDRs), which are time-series observational data of sufficient length, consistency, and continuity to record effects of climate change. Examples of CDRs include calibrated radiances, surface reflectance, and surface temperature.

[5] To learn more, see *Thriving on a Changing Planet: A Decadal Strategy for Earth Observations from Space*, which can be viewed and downloaded from *https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth*.

[6] Historically, every two years (since 2007) NASA's Earth Science Division has conducted a review of its missions that are in *extended operations*—meaning they have completed their specified prime mission—to assess their operating status, success in achieving mission goals, and merit for continued operation. Moving forward, such reviews will be taking place every three years.

[7] This refers to Research Opportunities in Space and Earth Science (ROSES) program element *A.37*: The Science of Terra, Aqua, and Suomi NPP.

NOAA-20 VIIRS instruments. He reported that the MODIS instruments on both Terra (nearly 19 years after launch) and Aqua (more than 16 years after launch) and their onboard calibrators (OBCs) continue to operate and function nominally. Likewise, both Suomi NPP (~7 years after launch) and NOAA-20 (~1 year after launch) VIIRS and their OBCs continue to operate and function nominally. He stated that challenging issues identified for both MODIS and VIIRS will be investigated and addressed for future calibration improvements in support of their data processing/reprocessing. He also added that more efforts are needed to better understand the calibration differences among sensors (Suomi NPP and NOAA-20 VIIRS; and Aqua MODIS) and to help generate consistent data products of high quality. The Calibration Workshop provided an opportunity to delve deeper into the topics Xiong summarized in this presentation.

Kerry Meyer [GSFC] summarized the Atmosphere Discipline's Cloud Team's assessment of relative differences in shortwave radiometry between Suomi NPP VIIRS and Aqua MODIS. He noted that long-term climate data records require merging the observational records of multiple instruments (e.g., MODIS and VIIRS), and that for geophysical product continuity between sensors, relative radiometry (and radiometric stability) is particularly fundamental to the Cloud Team's physical retrievals. He pointed out that it is much more challenging for solar channels, where the absolute reflectance specifications can be greater than the expected climate change signals, and that for cloud optical properties, relative radiometric offsets (even those within specified instrument uncertainties) can induce large nonlinear intersensor retrieval differences. Then Meyer discussed a plan of action, being used by the Cloud and Aerosol Algorithm Teams, that adds radiometric adjustment factors into the L2 code to reconcile radiometric-induced retrieval differences.

Bryan Baum [Science and Technology Corp. (STC)—*Suomi NPP Team Leader*] provided his perspective on achieving continuity from MODIS to VIIRS. He demonstrated the ability to construct infrared (IR) radiances for imagers based on imager–sounder data fusion, most recently the construction of Aqua MODIS-like channels for VIIRS. This methodology has been expanded to AVHRR/IASI and AVHRR/HIRS.[8] He also stressed the importance of moving from *instrument teams*, which were common 20 years ago, to *measurement teams*—because scientists need data continuity datasets that extend beyond the lifetime of a single instrument. The priority of the Terra/Aqua/Suomi NPP program is to achieve the best product continuity possible; this may necessitate use of ancillary data from other polar-orbiting and geostationary (GEO) sensors.

Chris Barnet [STS—*Suomi NPP Sounder Team Leader*] discussed the Community Long-term Infrared Microwave Coupled Atmospheric Product System (CLIMCAPS). CLIMCAPS is a NASA continuity product system that is based on the NOAA-Unique Combined Atmospheric Processing System (NUCAPS) and the use of AIRS/AMSU (on Aqua) and CrIS/ATMS (on Suomi NPP and NOAA-20) continuity products for cloud feedback studies.[9] CLIMCAPS uses the NASA GEOS-5[10] product for retrieval initialization. He described the work that has been done to create a hyperspectral sounding continuity product and showed examples of retrieval products that meet the needs of three communities: weather (e.g., extreme events), climate (e.g., processes, long-term trends), and composition (e.g., trace gases and air quality). He stated that NUCAPS is supporting real-time-weather and air-quality applications, and that the NASA continuity product will focus on developing a long-term (2002–2040) record for AIRS/AMSU and CrIS/ATMS. He concluded by stating that CLIMCAPS is designed to support community needs, asking participants how CLIMCAPS could support their research.

MODIS/VIIRS Aerosol Algorithms Status and Atmosphere Discipline Science

Steve Platnick [GSFC—*MODIS Atmosphere Discipline Leader*] chaired this session. These presentations focused on determining aerosol optical properties and science using MODIS and/or VIIRS. They addressed topics that ranged from aerosol-related algorithm development to application of the resulting data products. (See Table 1 in the white paper at the URL referenced earlier for details.)

MODIS/VIIRS Cloud Algorithm Status and Atmosphere Discipline Science

Steve Ackerman [University of Wisconsin–Madison—*VIIRS Atmosphere Discipline Leader*] chaired this session, covering cloud algorithms and a variety of science topics related to the Atmosphere Discipline. The presentations described topics that ranged from the characteristics and effects on other measurements of

[8] AVHRR stands for Advanced Very High Resolution Radiometer, which has flown on a series of NOAA, NASA, and international platforms since 1978; the last AVHRR launched in 2018 on the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT's) MetOp-C platform. IASI stands for Infrared Atmospheric Sounding Interferometer, which has flown on MetOp-A, -B, and -C. HIRS stands for High-resolution Infrared Radiation Sounder, which also flies on the MetOp series.

[9] AIRS stands for Advanced Infrared Sounder, and AMSU stands for Advanced Microwave Sounding Unit. CrIS stands for Cross-track Infrared Sounder, and ATMS stands for Advanced Technology Microwave Sounder.

[10] GEOS-5 stands for Goddard Earth Observing System Model, Version 5, which is run by the Global Modeling and Assimilation Office at GSFC.

several physical parameters (e.g., aerosols, ice crystals) to new approaches for detection and mapping of such phenomena. (See Table 2 in the white paper at the URL referenced earlier for details.)

Day 2

The second day of the meeting began with three more presentations related to the Atmosphere Discipline. After that the focus moved to the Land Discipline for the remainder of the morning. The afternoon was dedicated to parallel breakout sessions held by the Land and Atmosphere Disciplines.

MODIS/VIIRS Atmosphere Discipline Science (continued)

Bryan Baum was the chair of this short session. All of the presentations in this session described efforts to incorporate data and products from multiple sensors into their investigations. The scientific studies are continuing to evolve from single- to multiple-sensor data fusion efforts. (See Table 3 in the white paper at the URL referenced earlier for details.)

MODIS/VIIRS Land Science Analysis

Chris Justice [University of Maryland—*MODIS–VIIRS Land Discipline Co-Leader*] was chair of this session (and the Land Breakout Discussion that followed in the afternoon of the second day). His opening remarks for this session focused on the MODIS-to-VIIRS transition particularly as it applies to Land products, from the initiation of MODIS on EOS Terra to today. With such a continuous history, we now have the basis for a long-term and—with sophisticated reprocessing techniques—a reliable data record—essential for studying the impact of climate changes. Further, explicit quality assurance procedures have been developed and are routinely implemented at the Land Science Investigator-led Processing Systems (SIPSs).[11] He noted that the data are readily and widely accessible through a variety of means.

Justice went on to describe the relationship between MODIS and VIIRS in terms of objectives, design, and implementation—and why there are differences. Data continuity is further enhanced by noting that in many cases the VIIRS data products have been developed using the heritage algorithms from MODIS, with MODIS PIs heavily involved in the process. As Paula Bontempi showed in her remarks in the Opening Session, some MODIS products, including several land products, have been orphaned (i.e., they will not continue with VIIRS). Justice explained some of the reasons for the lack of continuity between MODIS and VIIRS, particularly in the context of Land algorithms and data products—see Introduction to this article and Justice's full presentation for more details.

Despite the continuity challenges that must be overcome, the transition between these two instruments presents an opportunity for a Research-to-Operations (RtO) transition. Opportunities often come coupled to challenges; in this case the challenge is for NASA and NOAA to figure out ways to work together for a smooth transition from RtO [i.e., from NASA MODIS (EOS) and Suomi NPP VIIRS to NOAA JPSS series, e.g., NOAA-20]. The science community already has a long-term record of coarse-resolution observations (with the previous transition from AVHRR to MODIS) but this time, with the operational VIIRS instrument also being a science-quality instrument, the transition is from one science-quality instrument to another.

Justice then reviewed the MODIS proposals related to Land, which were selected from the most recent TASNPP call. He showed a list of proposals continued from the previous selection (referring to the 2014-2017 ROSES call—*Science of Terra and Aqua*) that are undertaking new science or developing new data products under the TASNPP call. After that, he quickly ran through the ongoing projects (funded through MODIS Maintenance) that are part of the recent Senior Review and gave an update on the status of each. He encouraged participants to visit the Poster Session to learn more.

Justice ended his remarks with a summary slide of the foci for the Land Team discussions during the afternoon's breakout session. The overarching theme of all his bullet points was for the community to help develop a long-term strategy for NASA Land Products.

Miguel Román [GSFC—*MODIS–VIIRS Land Discipline Co-Leader*] followed with an overview of the Land data products from Suomi NPP. He showed a flowchart of the NASA VIIRS Land Product Interdependencies. His emphasis was on the impact that the orphaned products from the most recent TASNPP call will have on the flow of data products. He said that as much as possible, MODIS-equivalent Collection 6 products will be used to mitigate effects of orphaned products.

Román then discussed the current status of the VIIRS Land Processing SIPS for Version 1.0 of the Suomi NPP VIIRS algorithm. He also looked ahead to plans for reprocessing efforts beyond Version 1.0, and went on to show examples of VIIRS Land products in action. He emphasized the current continuity between MODIS and VIIRS, noting that several data products (e.g., active fires, cryosphere) show areas where using VIIRS data clearly improves over results obtained with MODIS. Román closed by describing validation activities for VIIRS.

[11] ESDIS supports data processing by providing SIPSs for processing EOS standard products. Most SIPSs are under the direct control of the instrument principal investigators/team leaders (PIs/TLs) or their designees, and typically collocated with the PIs/TLs.

The remainder of this session consisted of four presentations on selected VIIRS Land products, with topics ranging from algorithm improvement efforts for several products to the development of the "Black Marble" view of Earth's surface at night. (See Table 4 in the white paper at the URL referenced earlier for details.)

Discipline Breakout Sessions

The two parallel sessions summarized below took place on the afternoon of the second day of the meeting.

Atmosphere

Steve Ackerman and **Steve Platnick** facilitated the Atmosphere Breakout discussion, which intentionally emphasized open discussion over a series of presentations on specific research topics. Discussion topics focused on how to efficiently and effectively produce useful EOS–Suomi NPP/JPSS continuity data products for science team investigators and the larger community. Ackerman and Platnick began with some opening remarks to set the tone for the discussion. Ackerman reported that project summaries, as represented as two-page slides, were collected from all Atmosphere Science team PIs and will be distributed to the Atmosphere Team.[12]

At the request of the facilitators, **Kevin Murphy** [NASA HQ—*NASA Program Executive for Earth Science Data Systems*] then spoke to clarify some questions that had come up during and/or after Paula Bontempi's remarks in the Opening Plenary concerning the status of orphaned products. He explained that if a product is supported only through Senior Review MODIS Maintenance or MEaSUREs,[13] the SIPS is still tasked with production as long as the PI can support the product. This includes archiving and delivery of the data through the L1 and Atmosphere Archive and Distribution System (LAADS). On the other hand, if PIs are no longer funded, then they need to indicate that the product is no longer supported (i.e., orphaned) and that SIPS can only continue to support orphaned products until the product "breaks," e.g., if the product is not compatible with a new production system.

Liam Gumley [University of Wisconsin-Madison] gave the only formal presentation during this breakout, following up on Murphy's comments as regards orphaned atmosphere products as they apply to the Atmosphere SIPS. He then explained that the Deep Blue Aerosol (AERDB) products have been reprocessed four times in the past year, and showed an example using Worldview (defined in footnote 18 on page 14). He also showed an example of the Cloud Mask (CLDMSK) products in Worldview and demonstrated the impact of the Cloud Top and Optical Properties (CLDPROP) product by showing comparison of L3 data processing versus swath width. (For a breakdown of the Atmosphere data products, see Table 5 in the white paper at the URL referenced earlier.)

The discussion then turned to the importance of stewardship. The Atmosphere Discipline affirmed its support for the NetCDF4[14] data format for continuity products and for MODIS future collections.

Following Gumley's presentation, there was more discussion on product documentation and publications. Specifically, clarifying the definitions of and need for user guides and Algorithm Theoretical Basis Documents (ATBDs), along with the history. The consensus of the Atmosphere Team was to focus on user guides, which refer to previous ATBDs and published papers but are more directly relevant to users than traditional ATBDs. Continuity product user guides have been written and are hosted at LAADS. Science team investigators asked to provide input on the documents. Next there was discussion of the status of the products and the schedule, focusing on some continuity challenges and remaining uncertainties.

The topic of continuity challenges between MODIS and VIIRS arose again in this breakout discussion, specifically: *How do the algorithm groups plan to demonstrate that products have continuity with earlier datasets?* Discussion between algorithm developers and science investigators suggested that continuity depends on product usage. Current foci of developers include developing time series across large regions, doing pixel-level intercomparisons (to the extent possible), and using other independent methods (e.g., ground-based networks).

With regard to uncertainty, the consensus was that there is no single/simple answer or methodology to determine product uncertainty, as it depends on the part of the geophysical parameter space being observed and what datasets or combination of datasets are used. The discussion touched on several different approaches that Atmosphere Algorithm developers use.

There was also conversation about the status of L3 data products, which while not explicitly proposed in the TASNPP call—were not orphaned. After that came a discussion about how to address issues in relative calibration between VIIRS and MODIS. Long-standing questions remain, such as: *How often do we need to change coefficients? How do we keep science quality in the forward stream?* No decisions were made with regard to those questions.

[12] These summaries can be found at *https://www.ssec.wisc.edu/mvac/october-2018-meeting*. Note that some Team members had just received funding when the meeting took place, and thus did not have slides compiled.

[13] MEaSUREs stands for NASA's Making Earth Science Data Records for Use in Research Environments.

[14] NetCDF is a set of software libraries and self-describing, machine-independent data formats that support the creation, access, and sharing of array-oriented scientific data.