National Aeronautics and Space Administration

the earth observer

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Editor's Corner

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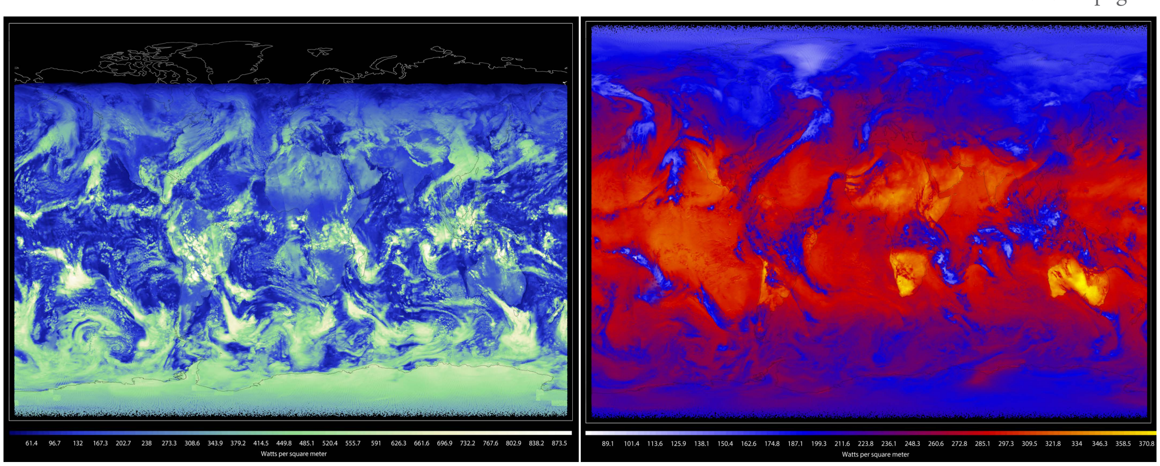
NASA will commemorate the 60th anniversary of its establishment later this year, with various milestones being celebrated throughout the year. For example, January 31, 2018, marked the 60th anniversary of the launch of *Explorer 1*, the first U.S. space satellite.[1] In this year of milestones, it seems fitting that the first editorial of 2018 highlights results from an assessment of missions in extended operations, provides a status on recently launched assets that build on heritage missions, and reports on the release of recommendations for the prioritization of Earth science observations in the coming decade.

In our last issue we reported on the successful launch of two new missions: JPSS-1, which launched on November 19, 2017, and TSIS-1, which launched on December 15, 2017. JPSS-1 continues to go through early checkout for each of the five instruments onboard. Our last issue highlighted the "first light" from the ATMS instrument, and the CERES instrument released its first public images on January 10, 2018. Dubbed Flight Model 6 (FM6), CERES is actually the seventh CERES instrument to fly.[2] FM6 builds upon an energy balance data record that goes back to 1997 via CERES, and as far as 1984 via the Earth Radiation Budget Experiment (ERBE).[3] Thanks to rigorous prelaunch calibration efforts, FM6 is the most accurate broadband radiometer that NASA and NOAA have flown to date. Lessons learned from on-orbit operations of previous CERES instruments were used to characterize FM6. To learn more about CERES FM6, visit *https://ceres.larc.nasa.gov/jpss1_ceres.php*.

[1] *The Earth Observer* reported on this pioneering space launch on its 50th anniversary in 2008. See the Editorial of the March–April 2008 issue of *The Earth Observer* [**Volume 20**, **Issue 2**, p. 4], as well as the iconic photo on that issue's front cover.
[2] The first CERES instrument [Proto Flight Model (PFM)] flew on the Tropical Rainfall Measuring Mission (TRMM) in 1997. Two instruments fly on both EOS Terra [FM1 and 2] and Aqua [FM3 and 4]; CERES FM5 is currently flying on the Suomi-NPP satellite mission.
[3] ERBE actually flew on three different satellites: the Earth Radiation Budget Satellite launched in 1984 from the Space Shuttle *Challenger*; the other two ERB instruments were included on the NOAA-9 and NOAA-10 satellites launched in 1985 and 1986, respectively.

continued on page 2



The covers on the Clouds and the Earth's Radiant Energy System Flight Model 6 (CERES FM6) opened January 5, 2018, allowing it to scan Earth for the first time. CERES FM6 began scanning Earth at approximately 1:25 PM January 5. On January 10, scientists used those scans to produce the "first light" images. In the shortwave image [*left*], white and green shades represent thick cloud cover reflecting incoming solar energy back to space. Compare that with the darker blue regions, which have no cloud cover, to get a sense for just how much clouds can affect the balance of incoming and outgoing energy on Earth. In the longwave image [*right*], bright yellow regions are the hottest and emit the most energy out to space. Dark blue and bright white regions, which represent clouds, are much colder and emit the least energy. **Credit:** NASA

www.nasa.gov

In This Issue

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

TSIS-1 joins several other NASA Earth-observing instruments on the International Space Station. The instrument was successfully installed on the ExPRESS Logistics Carrier (ELC) on December 30, 2017, and is currently conducting checkout operations.

TSIS-1 has two instruments: the Total Irradiance Monitor (TIM) and Spectral Irradiance Monitor (SIM), integrated into a single payload on a pointing platform. Both are provided by the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado. TIM will continue a 40-year record of Total Solar Irradiance (TSI) data, enabling a better understanding of the influence of solar energy variations on Earth's climate. SIM will measure the spectral distribution of the Sun's energy at an unprecedented accuracy and precision, to improve our understanding of how solar energy affects different atmospheric layers and other parts of Earth's system. The LASP team started acquiring TIM data in January and plans to begin taking SIM measurements in February.

TSIS-1 builds on the heritage of the venerable SORCE mission, which celebrated its fifteenth anniversary on January 25, 2018, but is likely nearing the end of its mission. Both TSIS instruments are upgraded versions of the same instruments that flew on SORCE. The overlap in TSIS-1 and SORCE measurements will allow for intercomparison between the sensors on both satellites and assure the continuity of the high-quality data record of TSI that dates back to 1978.[4]

In addition to these new missions, on December 15, 2017, the U.S. Geological Survey (USGS), in cooperation with NASA, announced the members of the Third (2018–2023) Landsat Science Team (LST), which is set up to provide technical and scientific input to USGS and NASA on issues critical to the continued success of the Landsat program. The specific goals for this new team are to ensure that Landsat 9 data, and relevant data from future Landsat missions, are completely integrated with past Landsat data for the purpose of meeting the needs of current users and enabling new applications. In addition, they will work to ensure that data from international sources (e.g., the European Space Agency's Sentinel-2 missions), as well as commercial sources, are synergistically exploited with the Landsat record. **Jeff Masek** [GSFC] and **Tom Loveland** [EROS] are the LST agency co-chairs for their respective agencies. The full list of science team members can be found at *https://landsat.usgs.gov/2018-2023-science-team*. Landsat 8 celebrated five years in orbit on February 11, 2018; both Landsat 7 and 8 continue to operate nominally. Landsat 9 is scheduled for launch NET December 2020. Turn to page 21 of this issue to read a summary of the most recent Landsat Science Team meeting, which gives more details on the current state of Landsat and its future plans.

[4] A TIM instrument also flies on Total Solar Irradiance (TSI) Calibration Transfer Experiment [TCTE], which launched in 2013 as a payload onboard a U.S. Air Force Test Program Spacecraft know as STPSat-3.

In other Landsat-related news, in November 2017, after more than 15 years of research and writing, the Landsat Legacy Project Team, in collaboration with the NASA History Office, released "Landsat's Enduring Legacy." The book was published by ASPRS under a NASA Space Act Agreement. The release was celebrated on November 15, 2017, at the Pecora-20 meeting in Sioux Falls, SD, followed by an event held at NASA's GSFC on January 30, 2018. At the latter of these events, two of the co-authors, **Darrel Williams** [GST—*Former Landsat Project Scientist*] and **Sam Goward** [UMD—*Former Landsat 7 Science Team Leader*], presented highlights of Landsat's long and rich history. This colorful publication summarizes Landsat's fascinating 45-year history and is a fitting tribute to the value of Landsat. The future of Landsat continues to evolve but it clearly builds on a solid foundation that has been established over more than four decades of continuous imaging of our home planet. Further details can be found at *https://www.asprs.org/landsat*.

Periodically, the Earth Science Division (ESD) conducts a Senior Review of missions in *extended operations*—meaning they have completed their prime operations period. The latest of these reviews, now entering a 3-year cycle, was conducted in spring 2017 covering seven long-running ESD missions seeking additional extensions (Aqua, Aura, CALIPSO, CloudSat, QuikSCAT, SORCE, and Terra) and three ESD missions in their first review (GPM, OCO-2, and SMAP). The CATS, TCTE, and DSCOVR EPIC and NISTAR instrument projects were also reviewed.

The Senior Review Subcommittee (SRS) was tasked with reviewing proposals submitted by each mission or instrument project team for extended operations and funding primarily for the next 3 fiscal years (FY18-20), as well as for FY21-23. The evaluations considered the scientific value, technical performance, proposed costs, and broader national interests associated with extending each mission. The SRS focus was foremost on the scientific merit, data product quality, and relevance to NASA Earth science goals and strategic plans. Subpanels were convened to provide in-depth evaluations of technical and cost issues as well to assess non-research use of these data by other federal agencies via a national interest subpanel. Overall, the SRS was unanimously impressed that all 13 reviewed missions/instrument projects have made unique and important contributions to NASA Earth science objectives and other agency needs and recommended their continued funding.[5]

However, a specific Subcommittee recommendation was for the Aura TES instrument to stop operations because of on-going Interferometer Control System translator motion failures. With ESD concurrence, TES was successfully decommissioned as planned on January 31, 2018. Though the subcommittee recommended continuation of EPIC and NISTAR operations and science, subsequent ESD guidance was to defer to the President's FY18 Budget Request for termination of the two instruments unless explicit appropriation action was given to continue operations. Since the SRS report, CATS ended operations onboard the ISS after a power and data system failure in October 2017 (see previous editorial). Turn to page 4 for further details from the 2017 Senior Review report.

Meanwhile, looking toward the future, the National Academies of Sciences, Engineering, and Medicine, led by the Space Studies Board in collaboration with other Earth Science related boards, has released the second Decadal Survey for Earth Science and Applications from Space. On January 5, 2018, a presentation/webinar took place, during which Survey Steering Committee co-chairs, **Waleed Abdalati** [University of Colorado, CIRES—*Director*] and **Bill Gail** [Global Weather Corporation—*Technology Officer*], summarized the survey results.[6] This report provides direction intended to help NASA, NOAA, and USGS as they develop plans for the next decade [2017–2027] of observations. Unlike its predecessor,[7] the second Decadal Survey does not focus on specific missions, rather it prioritizes key science questions and observations that need to be addressed over the next decade while leaving implementation details to the agencies. In particular, the report discusses the following three program elements along with targeted observations and candidate measurements for each: *Designated* (medium and large cost missions); *Explorer* (a new competitive program element for medium-size instruments and missions); and *Incubation* (new program element focused on priority observational investments). In addition to continuing the existing Earth Venture element, the report recommends a new component for low-cost sustained observations. Finally, the report notes that the underlying assumption for all recommendations is that existing and previously planned observations in the *Program of Record* are implemented as planned. I encourage all our readers to download the report for further details.[8] ■

[5] The full report contains details on specific recommendations for each mission. It is available at *https://smd-prod.s3.amazonaws.com/science-pink/s3fs-public/atoms/files/2017-NASA-ESSR_V2_FINALcorrected.pdf.*

[6] The release event was live-streamed and can be viewed at *https://vimeo.com/249845803*.

[7] The first Earth Science Decadal survey was published in 2007 [covering 2005–2015] and can be found at *https://www.nap.edu/catalog/11820/earth-science-and-applications-from-space-national-imperatives-for-the*.

[8] To read the full report, see *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observations* (2018)—*https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth*.

Note: List of undefined acronyms from the *Editor's Corner* and the *Table of Contents* can be found on **page 44**.

Summary of 2017 Earth Science Senior Review Findings

This material was taken directly, with mild editing, from the NASA Earth Science Senior Review Subcommittee Report - 2017, which can be viewed at *https://smd-prod.s3.amazonaws.com/science-pink/s3fs-public/atoms/files/2017-NASA-ESSR_V2_FINALcorrected.pdf*. It has been modified slightly for the context of *The Earth Observer*.

The Senior Review Subcommittee (SRSS) was unanimously impressed with the technical and scientific achievements produced by each mission, and by the unique and important contributions these platforms provide in furthering NASA and U.S. Earth science objectives. Collectively, these missions constitute an unprecedented Earth observation capability that continues to transform our scientific understanding of the Earth system, and their data also support a broad range of additional applications that greatly benefit other U.S. interests. The SRSS was also impressed that many of these missions continue to operate well beyond their designed lifetime—a fact that is a testament to high quality engineering, and exceptional on-going management and mission execution teams. The number of science and broader operational applications continues to expand, in part due to the reliability and longevity of these missions. The SRSS commended the hard work of the science and data product teams on each mission for their efforts to create, maintain, and extend this large and increasingly valuable suite of Earth observation measurement data records. The SRSS also wished to applaud the concept and implementation of pre-launch outreach to recruit and acquaint potential data users with upcoming missions. The Soil Moisture Active/Passive (SMAP) mission was a "pioneer" in implementing this *early adopter* approach, and it is encouraged for future mission developments. Finally, the SRSS was also pleased to see the forward-looking work by the A-Train mission teams to anticipate the upcoming orbit-adjustment needs of each platform and to fully consider the interplay amongst mission and science needs.

The SRSS's overall mission evaluations found that all thirteen missions merited summary science scores of very good to excellent. Breakdown of these scores is summarized in Tables 1 and 2—which can be found on pages 4 and 5 of the *NASA Earth Science Senior Review Subcommittee Report - 2017* referenced above. The report goes into detail on the specific recommendations for each individual mission.

In addition, the SRSS had the following specific findings:

1. The only suggested **reduction** in activity was sensor, rather than mission related; this being to terminate efforts to revive the severely-compromised Tropospheric Emission Spectrometer (TES) sensor on Aura.

2. As noted above, suggested **augmentations** were often recommendations to continue the mission rather than terminate as was the guideline for several aging missions [e.g., Solar Radiation and Climate Experiment (SORCE), Quick Scatterometer (QuikSCAT)].

3. International Space Station (ISS) Earth Science missions are a relatively new addition to the Earth Science Division (ESD) and to this mission extension review process. The SRSS concurred that this platform offers benefits and opportunities including cost efficiencies, as well as data collection in the low-inclination ISS orbit that offers valuable new data sampling in time and space. But the SRSS also relayed that it may be difficult to judge these ISS-sensor missions in comparison to more "standard" dedicated Earth Science missions. The SRSS cited several key distinctions between ISS and standard missions in the report. The most noteworthy of these was the shorter lifetime of these missions, which makes it difficult to assess the science merit and core data maturity, which in turn makes it harder to assess if ISS missions can directly contribute to climate data record generation and thus attract and develop operational users. Thus, the SRSS recommends that attention be given to defining future merit review criterion accordingly.

4. The addition of Aqua and Terra science algorithm team evaluations (mini-proposals) into this review process was viewed as a workable means of facilitating the desired transition, but NASA is encouraged to fully integrate these activities into the Terra and Aqua (or other mission) proposals in future senior reviews. ■

NASA's Outreach Activities at AGU

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

Introduction

The NASA Science Communications Support Office (SCSO) is the primary point of contact for NASA's Science Mission Directorate (SMD) and Earth Science Division for science exhibit outreach and product development. During the past fiscal year, the office supported activities at 26 domestic and international science conferences and public events by providing an inspiring and interactive communications exhibit and using a unique storytelling approach.[1] This allows a variety of audiences—worldwide—to connect with and understand NASA's science activities.

To close out 2017 the SCSO supported the largest Earth and space science meeting in the world—the American Geophysical Union (AGU) Fall Meeting, held December 11-15, 2017. 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 has chosen alternative meeting locations for both 2017 and 2018. The 2017 Fall Meeting was held in New Orleans, LA, at the New Orleans Ernest N. Morial Convention Center.[2] To view photos from AGU and other events supported by NASA's SCSO, visit *https://www.flickr.com/photos/eospso/albums*.

Prior to the event, the SCSO also organized the 2017 Annual 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 *2017 Annual Communications Meeting* in the next column.

2017 Annual Communications Meeting

The 2017 Annual Science Mission Directorate (SMD) Communications Meeting was held at the Sheraton New Orleans Hotel, Sunday, December 10. More than 100 NASA employees and contractors attended the daylong event. The attendees heard from **Kristen Erickson** [NASA Headquarters (HQ)—*Director of Science Engagement and Partnerships*] and three SMD division heads—**Michael Freilich** [HQ—*Director of Earth Science*], **James Green** [HQ—*Director of Planetary Science*], and **Peg Luce** [HQ—*Director of Heliophysics*]. In addition, **John Yembrick** [HQ—*Social Media Manager*] spoke about the agency's social media efforts and future plans. Following the lunch social and SMD breakout sessions, **Thomas Zurbuchen** [HQ—*NASA Associate Administrator for SMD*] shared his thoughts on communicating science and the interconnectedness between NASA's four SMD divisions—Earth Science, Planetary Science, Heliophysics, and Astrophysics. Participants left having been well informed about NASA's wide range of communications activities.

Events at the NASA Exhibit

As has been the case for 12 years, the SCSO organized and supported the NASA exhibit at the AGU Fall Meeting.[3] With help from representatives of NASA's outreach community, the 50 x 50-ft (~15 x 15-m) space allocated on the exhibit hall floor featured the Inspiration Theatre (i.e., the Hyperwall[4]), a Live Demo area, Data and Technology area, Sun-Earth area, and Planets and Moons area. Given this year's new meeting location, New Orleans-style street signs were used to direct visitors to various areas of the exhibit—see **Photo 1** on page 6. Attendees were encouraged to explore NASA-related science as they strolled along the four main "Avenues"—Interconnected, Impact, Innovation, and Inspiration. The exhibit represented the depth and breadth of NASA's science activities across several SMD divisions, including Earth Science, Planetary Science, and Heliophysics.

Throughout the week there were 108 scheduled presentations at the booth—72 science stories told

[1] The SCSO's 2017 Annual Report provides a broad overview of these activities, along with details about new Hyperwall stories, publications, social media, key partnerships, and more. To read the full report, visit *https://eospso.gsfc.nasa.gov/sites/default/files/publications/AnnualReport2017_508-v2.pdf*.

[2] The 2018 Fall Meeting will be held in Washington, DC. AGU's Centennial is taking place in 2019; plans call for a return to San Francisco to celebrate in the expanded and improved Moscone Center, December 9-13, 2019.

[3] Prior to this, there were a number of individual NASA exhibits (representing various projects, programs, etc.) scattered throughout the AGU exhibit hall. Now they are all combined in one location—dubbed "One NASA."

[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. Functioning as a key component at many NASA exhibits, the Hyperwall is used to help explain phenomena, ideas, or examples of global change. For more information about the Hyperwall, visit *https://eospso.gsfc.nasa.gov/content/about-nasas-hyperwall*.

in front of the Hyperwall and 36 Flash Talks[5]—see **Photos 2** and **3**. There were also 22 hands-on demonstrations in the Live Demo area—see **Photo 4**. The full schedule of events is available at *https://eospso.gsfc.nasa.gov/sites/default/files/publications/Program_508.pdf*.

[5] Flash Talks also took place on the Hyperwall but were quick seven-minute presentations. Hyperwall presentations have more of a storytelling feel and were 15 minutes in length.

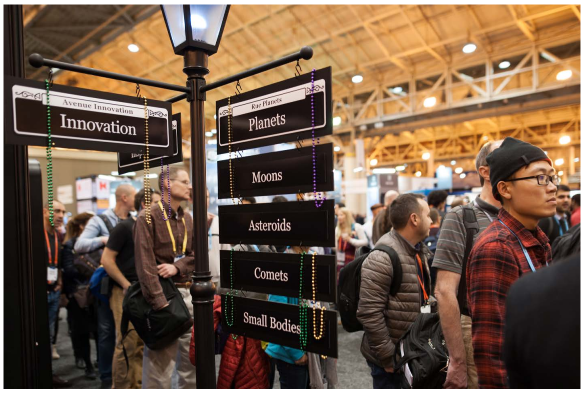


Photo 1. Street signs were located at various corners and intersections within the NASA exhibit at this year's AGU Fall Meeting. Pictured here, Avenue Innovation intersects Rue Planets, where attendees could learn about NASA's activities involving planets, moons, asteroids, comets, and other small bodies. **Photo credit:** NASA

Photo 2. Michael Freilich [Headquarters (HQ)—*Director of Earth Science*] gave the first Hyperwall presentation to a packed exhibit on opening night. His talk was titled *NASA's Earth Observation Capabilities: Meeting the Challenges of Climate and Environmental Change*. **Photo credit:** NASA

Photo 3. Pictured here, **Brian Campbell** [NASA's Goddard Space Flight Center (GSFC)—*Outreach Lead*] and an AGU participant demonstrated the Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) water density outreach experiment, called *Motion in the Ocean: Hands-On Water Density Demo*. **Photo credit:** NASA

Photo 4. At the Live Demo area in NASA's booth, attendees had an opportunity to visualize climate data using virtual-reality goggles. **Photo credit:** NASA

In addition to the NASA personnel who gave the scheduled talks, six winners of the *2017 AGU Data Visualization and Storytelling Competition*, a contest open to undergraduate and graduate students that focuses on innovation and creativity in presenting data to an audience in more easily accessible ways, presented their winning visualizations on the Hyperwall—see *Special Hyperwall Presentations* on page 7. The SCSO videographer recorded the presenters as they shared science stories in front of the Hyperwall during AGU. Individual presentations will be available to watch and download at NASA's Scientific Visualization Studio's YouTube page in the coming months (*https://www.youtube.com/channel/UCM2GOiW_Dxn1D7HHP80IrBg*).

The full schedule of events at the booth each day attracted large crowds and generated lots of questions and lively discussion among attendees. The 2018 NASA Science Commemorative Calendar was also one of the many resources that attracted attendees to the booth—see **Photo 5**. The calendar celebrates NASA's 60-year history and includes a special note from NASA Headquarters's Associate Administrator of SMD, **Thomas Zurbuchen**.[6] In addition to the calendar,

Photo 5. [*Left to right*] **Alex Young** [GSFC—*Associate Director for Science in the Heliophysics Science Division*], **Steven Clarke** [Office of Science and Technology Policy—*Senior Policy Advisor*], and **Thomas Zurbuchen** [HQ—*NASA Associate Administrator for SMD*] pose for a picture with the 2018 NASA Science Commemorative Calendar. **Photo credit:** NASA

[6] To view the 2018 NASA Science Commemorative Calendar online, visit *https://eospso.gsfc.nasa.gov/sites/default/files/publications/2018%20calendar_508.pdf*.

the exhibit offered a wide range of printed materials—including mission brochures, story booklets, fact sheets, and lithographs—that represent NASA's Earth science, planetary science, and heliophysics activities.

New this year, the exhibit featured a hands-on activity called *NASA's Living Timeline.* To become part of NASA's Living Timeline, attendees were asked to take a precut paper shape, record a personal memory involving NASA, and add their cutout to a spindle that represented the time period of their memory—see **Photos 6** and **7**. The intent of this interactive display was to demonstrate that we are all part of NASA's 60-year history.

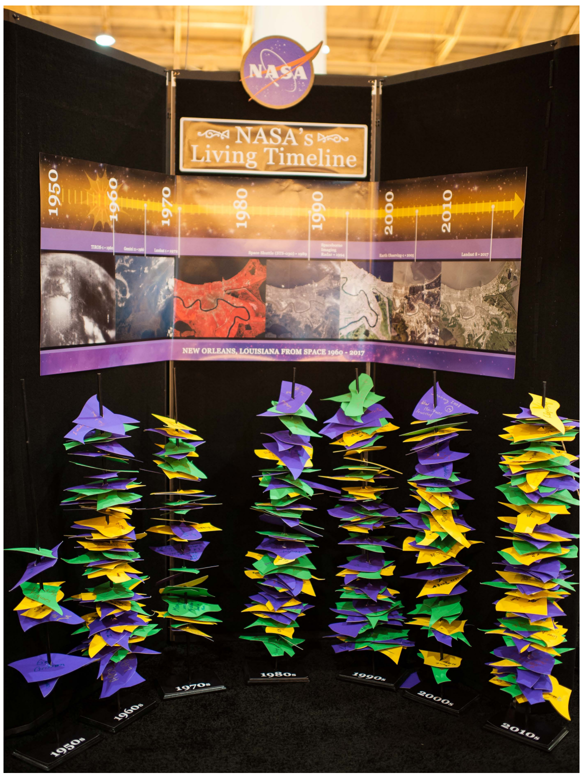


Photo 6. NASA's Living Timeline activity promoted attendees to recall a time when NASA's timeline intersected their personal timeline. Each spindle represented a decade, starting with the 1950s. **Photo credit:** NASA

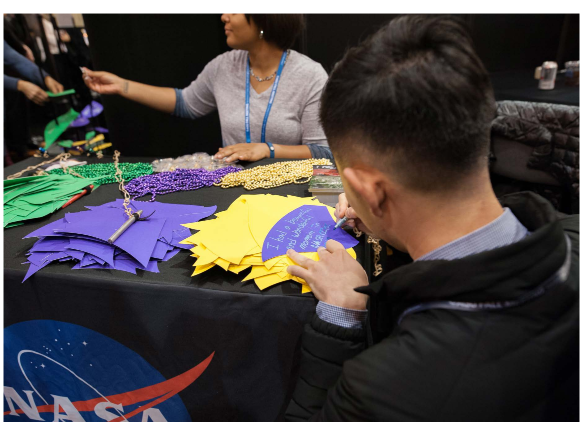


Photo 7. Participants were asked to record a memory of a time when NASA's timeline intersected their personal timeline, before adding it to the Living Timeline exhibit. **Photo credit:** NASA

Special Hyperwall Presentations

This was the second year for the *AGU's Data Visualization and Storytelling Competition*. In 2017, the six grand-prize winners had the opportunity to present their visual stories on the NASA Hyperwall in the exhibit hall at the AGU Fall Meeting. The 15-minute presentations took place on Tuesday, December 12, and Wednesday, December 13, during the lunchtime hour.

On Tuesday, December 12, **Thomas Zurbuchen** [HQ—*NASA Associate Administrator for SMD*] introduced three of the grand-prize winners of the *AGU Data Visualization and Storytelling Competition* and congratulated each of them on their achievement. **Photo credit:** NASA

On Tuesday, **Rebecca Lehman** [Yale University] discussed bringing big data to the U.S. Virgin Islands, **Yu Mo** [University of Maryland, College Park] presented information on climate feedbacks from coastal marshes, and **Jason West** [University of Colorado Boulder] discussed interseasonal variability in Earth's atmosphere and ocean.

On Wednesday, **Mahkameh Zarekarizi** [Portland State University] showed an online tool for probabilistic drought monitoring and forecasting across the U.S., based on satellite data assimilation, **Parker Hinton** [University of Colorado Boulder] shared a visualization of the Io plasma torus,* and **Andrea Albright** [University of Houston] discussed visualizing ocean waves using lidar.

To see the full list of grand-prize and runner-up winners, and to read each presenter's application, including a full summary of their work, visit *https://agu.secure-platform.com/a/gallery?roundId=28*. For more information on the AGU competition, visit *https://education.agu.org/grants/data-visualization-storytelling-competition/award-information*.

* The Io plasma torus is a ring-shaped cloud of ions and electrons surrounding the planet Jupiter.

Conclusion

The SCSO plans to represent NASA at a variety of scientific venues and public events in the coming year. 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[7] provide exciting new tools for NASA to communicate its science activities in a one-on-one basis with individuals in a manner that is unlike that used by any other space agency in the world. Looking ahead, the SCSO remains committed to implementing next-generation communication platforms as they become available. 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. ■

[7] 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.

Paul Newman Receives Award During Montreal Protocol 30th Anniversary Awards

Paul Newman [NASA's Goddard Space Flight Center—*Chief Scientist for Earth Sciences*] was among those who received the Scientific Leadership Award (one of several categories of awards given out) during the Montreal Protocol 30th Anniversary Awards Honour Ozone Heroes ceremony on November, 23, 2017 in Montreal, Canada. The co-hosts for the awards ceremony were: **Leyla Acaroglu** [Founder of Disrupt Design and Eco Innovators—*United Nations' Environment Champion of the Earth for 2016*]; **Sean Southey** [Populations Communications International (PCI) Media Impact—*Chief Executive Officer*] and Grammy Awards nominee **Rocky Dawuni** [Global Alliance for Clean Cookstoves—*Goodwill Ambassador*] who delivered a musical performance at the event.

The awardees were nominated and selected by an international jury comprising eminent environmental leaders based on the recommendations of a technical screening committee made up of experienced ozone experts from around the world.

I congratulate all the recipients of the awards for their extraordinary commitment and unwavering dedication to the Montreal Protocol. We also honour the contribution made by each individual, group, organization, and country towards making the Montreal Protocol a highly successful global environmental agreement that is protecting all life on Earth. We are all winners. We are all ozone heroes.

—**Tina Birmpili** [Ozone Secretariat*—*Executive Secretary*]

* The Ozone Secretariat only facilitated the process and was not involved in the evaluation and selection of the awardees.

The four individual winners, and representatives of the two group winners, are shown here with **Elizabeth Dowdeswell** [Lieutenant Governor of Ontario and Former Executive Director of UN Environment]. **Paul Newman** is the third person from the right. Biographies of Newman and the other individual and group winners can be found on page 7 of the document found at *http://ozone.unep.org/sites/ozone/files/30th-MP-Anniversary/ozone-awards-recipients-bios.pdf*. This document also details the other Montreal Protocol 30th Anniversary Award categories and their recipients.

Interagency Workshop on Societal Applications of Satellite Data for Ocean Health and Fisheries

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Introduction

In addition to the crucial role the ocean plays in regulating Earth's climate, a healthy ocean benefits people as a source of food and livelihood. However, industrialized society is taxing ocean life through increased pollution, warming, changing chemistry, and over-fishing, which all threaten food, economic, and human security. Identifying and tracking marine biological indicators and their response to multiple stressors can guide sustainable management and conservation efforts.

From the vantage point of space, Earth observation by satellites allow for global ocean monitoring in the present and offer even greater potential for the future. Ocean-color sensors measure light reflecting off the water, yielding valuable ecological information such as the concentration of chlorophyll and detrital material, both indicative of the state of ocean biology and its overall health. Satellite remote sensing of ocean color is challenging because it requires a cloud-free view and the subtraction of contributions from the intervening atmosphere. Furthermore, the ocean is dynamic and constantly changing, in a way that is more similar to weather systems in the atmosphere than vegetation on land, which has a slower rate of change.

To initiate a discussion on the opportunities and challenges of Earth observation for the ocean sector, NASA and the World Resources Institute (WRI) organized a one-day, interactive workshop that focused on current and future uses of ocean satellite data products to support decision making in the context of ocean health, fisheries, and human security. The workshop took place on November 2, 2017, at WRI Headquarters in Washington, DC. The meeting was also live-streamed via *Adobe Connect*. More than 150 local and remote participants came from a wide range of communities, including satellite data providers, current and potential new data users from diverse domestic and international governmental agencies, nongovernmental organizations, and private businesses. The attendees represented a variety of backgrounds including research, resource management, policy, national security, public health, education, and the fishing industry. Also in attendance at the workshop was **Paul Doremus**, the Chief Operating Officer of the National Oceanic and Atmospheric Administration's (NOAA) Fisheries and Acting Assistant Secretary for Conservation and Management.

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The workshop began with a series of overview presentations to introduce its goals and provide background on existing and emerging satellite data products. These presentations addressed agency programs and priorities for satellite applications. Four panel discussions were followed by a closing keynote address from **Paul Woods** [Global Fishing Watch (GFW)—*Chief Technology Offficer*] on GFW, a software package used for fishing vessel tracking. Several presentations during the meeting highlighted applications of GFW. The four panels engaged workshop participants in discussions on the themes of ocean health in the context of climate change, fisheries and ecosystem health, links between fisheries and human security, and resources and tools for accessing ocean satellite data products. To facilitate interaction between participants, the agenda budgeted time for formal discussion throughout the meeting and also provided ample opportunity for informal discussion and networking between participants during coffee breaks and lunch. A summary of meeting highlights follows. The full agenda, all presentations, and recordings are available from the workshop website at *http://www.wri.org/events/2017/11/nasa-wri-ocean-health-and-fisheries-applications-workshop*.

Introductions and Overview

Stephanie Uz [NASA's Goddard Space Flight Center (GSFC)—*Applied Sciences Manager*] opened the meeting by welcoming participants and outlining the day's agenda that was planned by NASA and WRI, working closely with NOAA—the agency responsible for fisheries management. The goals of the workshop were to introduce diverse members of the ocean sector to the latest ocean science and satellite data products that could aid their decisions, and to discuss end-user needs. A series of invited short presentations relevant to ocean health and fisheries were intended to highlight specific, relevant datasets and other existing and emerging products and tools, and to start a dialogue between data providers and data users on activities and needs across the ocean sector to increase the practical exploitation (application) of satellite data products. She concluded with three overarching questions for participants to consider throughout the workshop:

- Are you using satellite data right now? If so, how? If not, would you like to use it and how?
- Where do you see big data or product gaps?
- What are some barriers to data access?

The goals of the workshop were to introduce diverse members of the ocean sector to the latest ocean science and satellite data products that could aid their decisions, and to discuss end-user needs.

Jeremy Werdell [GSFC—*PACE*[1] *Project Scientist*] presented a brief explanation of satellite ocean color. Spaceborne radiometers measure the spectral distribution of light leaving the ocean surface from which the constituents influencing its color can be inferred, including information useful for fisheries management. Answering complex and emerging questions about changes at the base of the ocean food web requires knowledge about the types of phytoplankton that are present, and how they change with time. Werdell outlined the scientific justification to shift from current radiometric measurements (e.g., MODIS and VIIRS,[2] which measure at a series of discrete wavelengths) to spectroscopic ones [e.g., the Ocean Color Instrument (OCI) currently being designed for PACE, which will measure a continuous series of wavelengths]. Werdell ended with some comments designed to help demystify the acquisition, use, and analysis of satellite ocean color data products.

Woody Turner [NASA Headquarters (HQ)—*Program Manager for Ecological Forecasting*] introduced NASA as an organization that uses space-based satellites for basic and applied science activities, noting that increasingly novel uses of such data are just beginning to be explored. Turner outlined NASA's Applied Sciences Program within the Earth Science Division. He detailed three active Ecological Forecasting projects related to fisheries management, the detection and prediction of harmful algal blooms, and forecasting the beaching of high accumulations of *Sargassum*, a genus of brown macroalgae (seaweed). He introduced the Marine Biodiversity Observation Network (MBON) of the Group on Earth Observations Biodiversity Observation Network (GEO BON), which seeks to improve coordination of biodiversity data in the U.S., the Western Hemisphere, and ultimately the world. He concluded by mentioning the Applied Sciences Program's Early Adopters activity to generate simulated data for upcoming satellite missions before launch and the omnibus Research Opportunities in Space and Earth Sciences (ROSES) solicitation, through which NASA's basic and applied Earth Science programs solicit proposals for funding of projects across a wide range of disciplines.

Paul DiGiacomo [NOAA's Center for Satellite Applications and Research—*Chief of Satellite Oceanography and Climatology Division*] described many types of NOAA ocean observations and their societal applications. He clarified that Earth observing satellites cannot monitor fish populations directly from space, but do so indirectly by looking

[1] PACE stands for Plankton, Aerosol, Cloud, ocean Ecosystem, a next-generation ocean color satellite currently in mission design, with launch planned for 2022.

[2] MODIS stands for Moderate Resolution Imaging Spectroradiometer, which flies on NASA's Terra and Aqua platform; VIIRS stands for Visible–Infrared Imaging Radiometer Suite, which flies on the Suomi National Polar-orbiting Platform (NPP) and the recently launched Joint Polar Satellite System-1 (JPSS-1).

at the environmental conditions of ecosystems. NOAA is both a provider and user of satellite data for *environmental intelligence* in support of its long-term goals. Legislation mandates that NOAA prioritize ecological forecasting of harmful algal blooms, hypoxia, pathogens, and habitat. Priorities are developed based upon stakeholder needs, NOAA capacity, and national significance. As capacity develops and expands, decision support forecasts improve and increase their effectiveness. For example, because so many endangered species are migratory, the goal is to use a dynamic approach, predicting species locations in near-real time (e.g., using Whale Watch,[3] Turtle Watch,[4] EcoCast—see **Figure 1**) to inform fishers to reduce *bycatch* (i.e., catching animals other than the target species), and redirect ship traffic or naval exercises away from marine sanctuaries. DiGiacomo mentioned other NOAA programs, informed by NOAA's diverse observation network (ships, aircraft, buoys, gliders, floats, satellites) and assets from other partners (NASA, National Science Foundation, U.S. Environmental Protection Agency, individual states, and academic institutions).

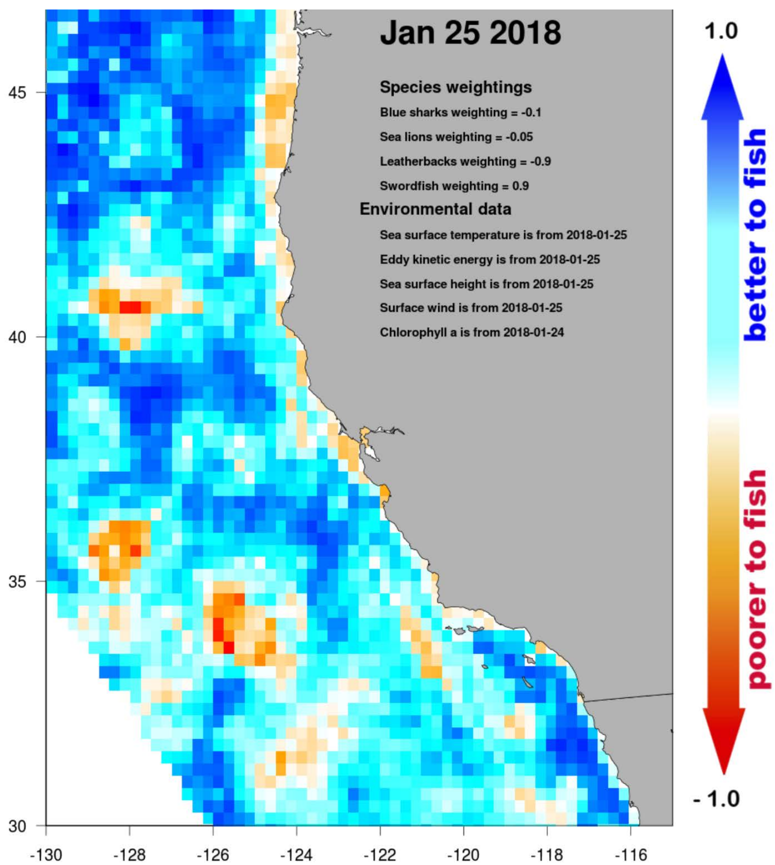

Figure 1: EcoCast is a NASA-funded dynamic management project that synthesizes satellite data with *in situ* observations in near-real time to give fishers and managers the ecosystem assessment tools they need to maximize productive catch while minimizing nontarget (unwanted) bycatch. The scale reflects areas that are better to fish (blue scale) and worse to fish (red scale). The EcoCast predictive map integrates multiple dynamic species distribution models that account for distribution of catch (swordfish) and bycatch (leatherback sea turtle, blue sharks, marine mammals). It builds upon the capabilities of WhaleWatch and TurtleWatch, mentioned in the text. **Image credit:** Hazen *et al.*, NOAA Fisheries/Southwest Fisheries Science Center

Christa Peters–Lidard [GSFC—*Deputy Director for Hydrosphere, Biosphere, and Geophysics Laboratory*] described NASA's Earth observations and applications programs. She showed several current examples of data relevant to the ocean including: maps created by the Global Precipitation Measurement (GPM) mission and Integrated Multi-satellitE Retrievals for GPM (IMERG); Landsat coastal water quality maps; and ocean color products derived from a variety of previous and current sensors, and modeled phytoplankton. She also touched upon several upcoming missions of interest: Ice, Clouds, and Land-Elevation Satellite-2 (ICESat-2); Surface Water and Ocean Topography (SWOT); and PACE. Peters–Lidard discussed NASA's Capacity Building Program, which seeks to engage current and future decision makers in a spectrum of

[3] WhaleWatch is a NASA-funded project coordinated by NOAA Fisheries' West Coast Region to help reduce human impacts on whales by providing near-real-time information on where they occur and hence where whales may be most at risk from threats, such as ship strikes, entanglements, and loud underwater sounds.
[4] TurtleWatch is a formerly NASA-funded tool that provides up-to-date information about the thermal habitat of loggerhead sea turtles in the Pacific Ocean, north of the Hawaiian Islands.

activities both in the U.S. and in developing countries, to improve access to NASA Earth science and data that cover a range of societal applications.

By working with Bloomberg to serve water risk data, WRI is able to reach 320,000 investors, helping to inform investments in water intensive sectors, such as power and agriculture.

Janet Ranganathan [WRI—*Vice President for Science and Research*] described WRI as a global nonprofit research institute that advances evidence-based approaches for more sustainable management of the planet. WRI is an avid user of NASA and NOAA Earth science data—but only uses a fraction of what could be used. She noted that "we are drowning in Earth science data" but it is not yet reaching all those who could use it to make more sustainable decisions. Such utility comes from WRI's Aqueduct open data platform, which provides globally consistent, sub-basin level data on water risk (i.e., quantity, quality, demand, future projections). By working with Bloomberg to serve water risk data, WRI is able to reach 320,000 investors, helping to inform investments in water intensive sectors, such as power and agriculture. Ranganathan concluded with a preview WRI's Resource Watch (*http://www.vizzuality.com/projects/resource-watch*), a free, interactive, open data platform for collaboration and action that will empower people with the information they need to more sustainably manage the world's resources. Resource Watch is scheduled to launch on April 11, 2018.

Discussion Summary

The discussion focused both on getting satellite data easily into the hands of nontraditional users and also sharing examples of how to use the data. **Mitchell "Mitch" Roffer** [Roffer's Ocean Fishing Forecasting Service (ROFFS), Inc.] had recently returned from Tanzania, where he said they have access to the data but lack the experience and ability to use it. People need on-line resources on how to use the data, so that they don't have to travel. (The fourth panel discussion on page 17 elaborates on specific resources and tools to help anyone access the data.) **Amita Mehta** [GSFC] commented that NASA's Applied Remote Sensing Training (ARSET) offers thematic online training for very local end users around the world. ARSET trains people from a variety of backgrounds—from government employees to farmers and fishers, including dam operators in small African countries. ARSET shares NASA and NOAA data and teaches people how to apply satellite data to themes such as water resources, air quality, ecological forecasting, and disaster management.

Carlos Del Castillo [GSFC—*Chief of Ocean Ecology Laboratory*] acknowledged that data producing organizations have a lot of data and amazing tools—but they are not necessarily intuitive to nonspecialists. Thus, tools need to be tested and evaluated before launch to prevent situations where tools are only understood by the people who made them. **Janet Ranganathan** agreed, noting that currently the largest fraction of funding goes into the production of data, and that additional funds need to be made available for the applications of the data. Coordination with development agencies and foundations could create more coherence.

Woody Turner reminded people about SERVIR,[5] a NASA capacity-building project in coordination with the U.S. Agency for International Development (USAID), to provide satellite-based solutions to address particular challenges. SERVIR applies Earth observations to support decision making in developing countries. Although it hasn't yet done much with fisheries applications, the project could be so encouraged. A discussion followed concerning the emphasis on training and experience with these international programs at the government level and the need to connect with true end-users (e.g., fishermen). The private sector and academia also need to engage in the discussion. The consensus was that there is much more to be done in this area. In this vein, the Canadian Space Agency started the Societal Applications in Fisheries and Aquaculture using Remotely Sensed Imagery (SAFARI) to connect users, particularly in India. Data providing agencies agreed that they have a long way to go to make a substantive impact at the user level.

[5] SERVIR is not an acronym. It is a Spanish word that means "to serve."

Panel 1: Ocean Health in the Context of Climate Change

Stephanie Uz [GSFC] moderated this panel, which focused on the big picture of how satellite data and other products indicate the ways in which the ocean is changing and how that impacts ocean biology. In addition to satellite data, assimilating data from many sources refines understanding of the role of ocean life within the Earth system, and improves our ability to predict and prepare for changes.

Steven Pawson [GSFC, Global Modeling and Assimilation Office (GMAO)] explained how NASA observations are used to constrain the physical state of the ocean in the Goddard Earth Observing System (GEOS) model for seasonal-to-decadal analysis and prediction and a subseasonal-to-seasonal model for monthly forecasts. He explained that GMAO is upgrading to a new model and compared their respective outputs. Pawson also discussed a more recent effort to constrain the biological state of the ocean using NASA's Ocean Biology Model, described its components, and showed some initial chlorophyll forecasting results in the Tropical Pacific.

Scott Doney [University of Virginia—*Professor of Environmental Change*] stated that climate change and other human impacts are directly affecting ocean life and health. New data analysis tools are emerging—such as seascapes (*http://www.marinebon.org/seascapes.html*), which provide a dynamic approach for identifying and monitoring marine habitats. Borrowed from the world of "big data," they provide a combination of satellite and *in situ* observations to offer a powerful approach for monitoring ocean ecosystem health, addressing ocean conservation challenges, and detecting ongoing changes that arise from natural variability and human impacts.

In addition to satellite data, assimilating data from many sources refines understanding of the role of ocean life within the Earth system, and improves our ability to predict and prepare for changes.

Mark Eakin [NOAA's Coral Reef Watch] discussed coral bleaching, and gave an overview of Coral Reef Watch's satellite-based products, as introduced in Paul DiGiacomo's earlier presentation. Coral Reef Watch products use data from both polar-orbiting and geosynchronous satellites. This tool gives managers the ability to predict coral bleaching, such as that which occurred between 2014 and 2017—the longest, most widespread, and likely, the most damaging thermal stress event ever. He ended by mentioning the recent film *Chasing Coral* (*http://www.chasingcoral.com*), which documents the state of coral reefs around the world and explored how they are vanishing at an unprecedented rate.

Panel 1 Discussion Summary

The main themes of the discussion with all participants included the importance of refining predictive capabilities through the assimilation of additional datasets. These include satellite data from the European Space Agency (ESA) and Japan Aerospace Exploration Agency (JAXA), and getting data developers into the field to interact with end-users to share resources and understand practical requirements. In an era of shrinking budgets, there is a need for more of this to be done online.

Mark Eakin discussed the hands-on workshops for resource managers, conducted annually with each U.S. Coral Reef jurisdiction in partnership with several international partners (e.g., SERVIR and the World Bank). Earlier funding for these activities has now largely disappeared, and there is a consequent need to put training and feedback tools online.

There was focused discussion on the impact that Hurricanes Irma and Maria had on coral reefs around the Virgin Islands and Puerto Rico. According to Eakin, damage assessments are still ongoing, limited by logistical limitations (e.g., fuel for boats). Reports from the Florida Keys indicate the extent of damage was not as bad as feared there, but was worse in the southern Keys compared to the northern Keys. NASA is currently funding a project to include more satellite data to predict coral reef disease in the Pacific.

There was a general discussion about resource constraints. **Scott Doney** noted that the American Association for the Advancement of Science provides a robust analysis of administration and congressional budgets. The current administration has proposed cuts for NASA Earth Science—including the PACE mission; similar cuts were proposed for NOAA. Several websites have detailed analyses of budget proposals.

Charlie Iceland [WRI] asked about the extent to which ESA and JAXA support monitoring of ocean temperature, acidification, and other parameters and whether agencies share resources. Several speakers offered that international collaboration is common and ongoing, thereby optimizing use of limited funding and other resources.

Panel 2: Fisheries and Ecosystem Health

Cara Wilson [NOAA Fisheries] moderated the fisheries and ecosystem health panel, which focused on the use of science and technology to improve local resilience and support decisions for sustainable fisheries. The focus was on the need to develop actionable information that takes advantage of the repeated, synoptic view afforded by satellites to improve health and safety, while minimizing waste and environmental impacts.

Camrin Braun [Massachusetts Institute of Technology/Woods Hole Oceanographic Institution] discussed the new paradigm for fisheries management. Traditionally, managers used a *static, catch-limited* approach for a given oceanic area, which ignores processes that operate on a variety of scales. Conversely, *dynamic* management incorporates changes in space and time in response to the shifting nature of the ocean and its species, and considers biological, oceanographic, and socioeconomic factors. He discussed oceanographic factors that impact fish habitats and how fish interact with ocean eddies. Improvements include observations at increasingly smaller scales. Planned NASA missions like PACE and SWOT will make measurements at finer spectral and spatial scales, respectively, to augment *in situ* data.

"As with every model I use such as weather and wind and swell, I watch them to see how it applies to my local conditions, and then I determine my own degree of accuracy and apply them to making decisions about how I manage the farm. When a domoic acid event occurs, I comb [through] the models to see how it relates to my situation."

—**Bernard Friedman**, Santa Barbara Mariculture Company, Santa Barbara, CA

Mitchell "Mitch" Roffer explained how his company uses satellite data to produce a value-added fish forecast product. He focused on ROFFS work with fisheries and aquaculture, beginning with satellite data, and giving examples of how they tailor specific products to meet their customers' needs, with the goal of sustaining and increasing what Roffer referred to as *catchability*. Roffer noted that optimal satellite products would be hourly, cloud-free, microwave sea surface temperature (SST) data, multispectral ocean color data at 250-m (~820-ft) spatial resolution, and global positioning system (GPS) data. He noted that his customers need data in real time, and such data are not always available.

Shelly Tomlinson [NOAA Ocean Services] addressed using satellites to forecast harmful algae blooms (HABs), which are associated with several human health and animal illnesses. While satellite imagery alone cannot distinguish a HAB from non-harmful algae—and is not useful for all species—it can be a useful tool when combined with other ecological data. Several algorithms have been developed to detect HABs using data from ocean color sensors (VIIRS, MODIS, and OLCI[6]). While this is an international problem, her specific examples focused on the U.S. She then proceeded to show four places where satellites are being used for HAB forecasting and monitoring: in the Gulf of Mexico, over Lake Erie, in California's coastal waters, and in the U.S. Pacific Northwest. Tomlinson also included a slide with personal testimonials from shellfish growers (e.g., see quote from Bernard Friedman on this page), fishermen, and marine mammal rescue centers (e.g., see quote from Richard Evans on page 19) about how they use this information.

Bernard Friedman [Santa Barbara Mariculture Company] described his experience as an aquaculture farmer who operates a 25-acre open-ocean shellfish farm one mile off the coast of Santa Barbara, CA, with annual production of about 100,000 pounds of mussels. Offshore shellfish farming has massive potential to provide healthy protein at a much less environmental cost than any other form of farming on this planet. His mussels provide a local source of seafood since their phytoplankton food source continuously and naturally renews itself. He stated that the meat quality found inside the shellfish is a direct indicator of ecosystem health: When the meat turns toxic, as it did during the El Niño of 2015-16, he would like to know in advance of the onset of harmful conditions—but often he does not.[7]

[6] OLCI stands for Ocean and Land Colour Instrument and flies on ESA's Copernicus Sentinel-3 mission.

[7] Learn more about Friedman's personal connection to satellite data in "Using Scientific Muscle to Grow Safer Mussels," posted on *The Earth Observatory—https://earthobservatory.nasa.gov/IOTD/view.php?id=91595*.

Panel 2 Discussion Summary

Monitoring ocean biology and ecosystem health from space is complicated by the intervening clouds and the fact that everything moves and changes. **Woody Turner** pointed out that the trade-offs between spatial, temporal, and spectral resolution is the key to what can be resolved. A future geostationary ocean color sensor (e.g., the proposed GEO CAPE[8] mission), combined with current satellite capabilities and improved models, would radically enhance our ability to derive actionable information about submesoscale, transient biological features. The 2017 Decadal Survey is setting priorities for missions in the next decade.[9]

The group discussed differences between the needs of aquaculture and those of the wild fishing fleet. **Bernard Friedman** said that policies lag offshore shellfish farming[10] practices, referring to offshore shellfish as the "canary in the coalmine," since they respond to various stressors before harmful levels of demoic acid (a neurotoxin found in algae) can be detected by other means, and enter into policy discussions. He would like advanced information about the types of plankton at his farm and when they turn toxic. **Shelly Tomlinson** pointed out that ecological modeling is a new domain, not as mature as dynamical models, and currently being assessed and refined.

Mitch Roffer described how forecasting wild fish stocks has economic impacts for ROFFS customers, who use them for strategic planning of their fishing fleet assets. In Tanzania, he recently used satellite data to help identify new fishing areas so that they could stop overfishing historical fishing sites and develop a properly managed, sustainable fishery. While spatiotemporal satellite data and models are useful for developing such broad plans, neither are yet reliable at the operational scale (i.e., submesoscale, hourly).

Camrin Braun emphasized the challenges posed by satellite data latency and infrequency, as weather fronts are in motion and a satellite image that is hours old can show a location hundreds of miles away from a current location. Some end-users expressed annoyance that agencies take a long time to quality-control data prior to sharing it, while many operational users do not require precise values, and actually prefer relative amounts (e.g., chlorophyll concentrations), but would prefer faster, near-real-time experimental products. Something that combines the speed, direction, and magnitude of a front would be useful, although preferred habitats are species specific. **Paul DiGiacomo** mentioned the importance of blending geostationary and polar products to fill gaps and create a truly operational product—not yet available for ocean color. As noted earlier, GEO-CAPE is proposed, but will not occur within the next five years.

[8] GEO CAPE stands for Geostationary Coastal and Air Pollution Events, and was one of the missions proposed in the 2007 Earth Science Decadal Survey—*https://www.nap.edu/catalog/11820/earth-science-and-applications-from-space-national-imperatives-for-the*.

[9] The second Earth Science Decadal Survey was released January 5, 2018. It is called *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observations* (2018), and is now available online at *https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth*.

[10] In 2016 NOAA published the nation's first regulatory program for offshore aquaculture in federal waters, intended to expand opportunities for marine aquaculture and meet the growing demand for sustainable local seafood.

Panel 3: Links Between Fisheries and Human Security

Charlie Iceland [WRI] moderated this panel, which focused on organizations that use ocean satellite data and products to inform decisions that assist society and human security. Quickly getting actionable Earth-observation information into easily usable tools is key to supporting tactical intervention.

Johanna Polsenberg [Conservation International] shared the Ocean Health Index (OHI, *http://www.oceanhealthindex.org*). The OHI is a mechanism for marine ecosystem-based management, defined in an easy-to-use global metric that can be used to monitor progress over time. This index was created to capture the human-ocean coupled system; distill it into easy-to-understand metrics; incorporate sustainability into all indicators; monitor progress and track through time; and motivate actions to improve ocean health. Thus far, limited satellite data have been applied, and used to monitor various phenomena—e.g., sea ice, mangroves, SST, ultraviolet radiation, and sea-level rise. Polsenberg discussed the 10 comprehensive goals of OHI and the core process to score them, and challenged participants to think about global or regional satellite data that could be applied.

Oceana has a team of analysts that use the maps in combination with other data to produce reports and to support campaigns to improve fisheries management around the world.

Beth Lowell [Oceana] introduced her organization, which is dedicated to international ocean conservation, and using satellite data to protect the ocean, with a focus on responsible fisheries management. Oceana's motto is: *"Save the oceans, feed the world."* She then described how illegal, unreported, and unregulated (IUU) fishing and seafood fraud are issues that undermine responsible fisheries management, and that sea-based traceability—while difficult—helps track seafood through the complex seafood supply chain. She also gave a preview of Global Fishing Watch (GFW),[11] an online, free platform that incorporates real-time commercial fishing activity data into useful maps, developed in coordination with scientists, data providers, and resource managers. Oceana has a team of analysts that use the maps in combination with other data to produce reports and to support campaigns to improve fisheries management around the world—see **Figure 2**. Recent projects include identifying hotspots of transshipping activity and discovering unlawful fishing activity typically just outside countries' exclusive economic zones, in order to stop it. Lowell explained that governments are recognizing the importance of publically sharing fisheries data to fight illegal fishing, e.g. Indonesia now publishes its data in GFW. Oceana and GFW are working with more governments to secure additional vessel tracking data.

[11] See **Paul Woods**' keynote address on page 19 to learn more about Global Fishing Watch.

Camrin Braun (middle) tags a shark to track its movement in the North Atlantic. In his presentation [see page 14], Braun mentioned that one of the challenges of fisheries management is that a single shark can cover lots of ground in relatively short time, as evidenced in Figure 2—by Oceana in which shark tracks are superimposed on a Global Fishing Watch map. **Photo credit**: Tane Sinclair-Taylor/MIT-WHOI

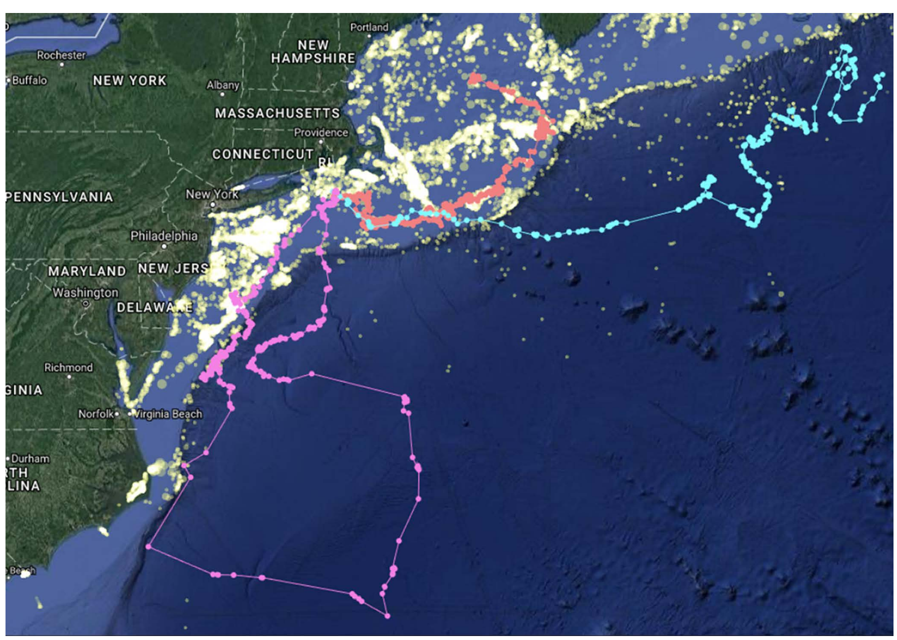

Figure 2: Example of a blue shark case study and a Global Fishing Watch workspace showing the interactions between three tagged shark tracks (red, blue, and pink dotted lines) and commercial fishing activity (white dots) in the Northwest Atlantic during June - September 2016. **Image credit**: Beth Lowell/Oceana

Christoph Aubrecht [European Space Agency/World Bank] noted that the wealth of the global ocean is conservatively estimated at $1.5 trillion U.S. dollars annually, and that almost 15% of the world's population depends on fisheries or aquaculture for livelihood. Unfortunately, in recent years, the health of the ocean has declined, leading to food insecurity and instability. In response, the World Bank promotes a *blue economy*—a sustainable ocean economy where economic activity is in balance with ocean health. Aubrecht described the *Earth Observations for Sustainable Development* (EO4SD) initiative with the development banks, that includes using EO in support of fisheries and aquaculture management. The main challenges include fast delivery of actionable satellite information and the reliability of the analytics. Persistence is an issue for tactical support and is being addressed through new, small satellites. The main concern is how to put these tools into the appropriate hands with a long-term sustainable framework.

Panel 3 Discussion Summary

The main themes of the discussion were about building capacity around the United Nations Sustainable Development Goals (UN SDGs), especially Goal 14: Conserve and sustainably use the oceans, seas, and marine resources. In particular, **Joanna Polsenberg** and others noted that it can be challenging for developing governments to handle big data, making it challenging for them to integrate products into their decision-support process and strengthen their ability to enforce regulations.

GFW is a success story in that regard: Use of the tool by developing countries has doubled, enabling them to better protect their territorial waters since most productive fishing areas are within the exclusive economic zone of countries. **Beth Lowell** said Oceana sees fisheries starting to recover once countries enforce scientifically-based catch limits, protect habitats where fish spawn, and reduce bycatch. The World Bank has also had success reaching local communities and has strong capacity-building programs via developmental banks to address local problems.

A discussion about how African nations make use of satellite data pointed to several areas of significant concern that workshop participants from Africa bought to the group's attention. **Christoph Aubrecht** asked with whom data providers should engage to increase capacity-supporting resource management and noted that the World Bank had a project in the western Indian Ocean dealing with oil spills related to piracy that successfully used synthetic aperture radar (SAR) imagery to identify and catch oil slick offenders and stop them.

Paul DiGiacomo described ongoing discussions with the Committee for Earth Observation Satellites (CEOS) and the challenge presented by SDG targets being socioeconomic, while data collected by Earth Observation providers are more statistically based. Workshops engaging stakeholders hope to explore practical scenarios to bridge this gap (e.g., GEO Blue Planet workshop in January).[12]

[12] The workshop is called *Implementing and Monitoring the Sustainable Development Goals in the Caribbean: The Role of the Ocean*, January 17-19, 2018, in St. Vincent and the Grenadines in the Caribbean. To learn more, see *http://www.gstss.org/2018_Ocean_SDGs*.

Panel 4: Resources and Tools for Using Ocean Satellite Data Products

Paul DiGiacomo moderated this panel on the satellite data products available for different levels of user engagement, from detailed scientific analysis to quick looks at global imagery. Before introducing the presentations on what users need and how to get appropriate tools and data to them, DiGiacomo specifically mentioned two relevant international efforts from the Group on Earth Observations (GEO): the Blue Planet network initiative, and AquaWatch, a water-quality information resource.

The challenge is in getting these data into the hands of interested nonscientists and training them to use them—a chasm between research and applications.

Carlos Del Castillo began by showing data from the Sea-viewing Wide Field-of-View Sensor (SeaWiFS) that shows the planet "breathing." He then gave some historical perspective, reminding participants of the humble beginnings of ocean color satellite data acquisition, and the contrast today, where there are many sensors, many satellites, and many different users from a variety of backgrounds. The challenge is in getting these data into the hands of interested nonscientists and training them to use them—a chasm between research and applications. NASA's ARSET has archived several excellent ocean color webinars useful for this purpose: see *https://arset.gsfc.nasa.gov/sdgs#SDG14* to learn more.

CoastWatch offers tools and tutorials for searching, downloading, analyzing, and imaging satellite data that enable easy access and use, including by nonexperts.

Jim Acker [GSFC, Earth Sciences Data and Information Services Center] endorsed Jeremy Werdell's introduction to ocean color and recommended his own book on the subject for those with a deeper interest in the history of ocean color.[13] He then gave overviews of three different analysis tools: Worldview (*https://worldview.earthdata.nasa.gov*), NASA Earth Observations, or NEO (*https://neo.sci.gsfc.nasa.gov*), and Giovanni (*https://giovanni.gsfc.nasa.gov/giovanni*). He contrasted each tool by using them to examine the seasonal Amazon River outflow plume. Worldview is primarily designed to provide near-real-time daily (or finer temporal resolution) data in layers that are easy to combine for data analysis. NEO gives 50 satellite datasets and is a useful tool for comparing up to three images or times. Acker demonstrated NEO's Data Probe and Transect capabilities. Giovanni contains both satellite and model output data, with several different visualization and analysis capabilities. One noteworthy capability of Giovanni is creating time series; another is creating a difference map between two output files (with Panoply). All of these NASA tools are available for viewing and analyzing remotely sensed data on-the-fly without having to download software.

Veronica Lance [NOAA—*CoastWatch/OceanWatch Program Scientist*] showed how NOAA CoastWatch/OceanWatch (*coastwatch.noaa.gov*),[14] provides fit-for-purpose global and regional, near-real-time, and science-quality time-series satellite data products. They are derived from NOAA and non-NOAA satellites for multiple environmental parameters. Global and regional satellite data products are converted into actionable information through assimilation with other data and models, and used to understand, manage, and protect ocean and coastal resources. CoastWatch offers tools and tutorials for searching, downloading, analyzing, and imaging satellite data that enable easy access and use, including by nonexperts.

[13] Learn more about what led Acker to write *The Color of the Atmosphere With the Ocean Below: A History of NASA's Ocean Color Missions* at *https://earthobservatory.nasa.gov/blogs/earthmatters/2015/09/28/some-insight-on-the-color-of-the-ocean*.
[14] NOAA CoastWatch/OceanWatch central office is in College Park, MD, with several nodes distributed geographically and among NOAA line offices such as Fisheries Service, Ocean Service, and Oceanic and Atmospheric Research.

Panel 4 Discussion Summary

We are data rich, but often information poor.

One focus of the discussion on resources and tools for using ocean satellite data products was on building value-added products and making sure they're useful to end-users. Returning to a topic raised in the Panel 2 discussion, having fast access to lower resolution than research-grade data products would have significant utility for appropriate groups, and intermediary arrangements through organizations such as WRI can help to bridge this divide. Applied Sciences projects that are funded through NASA require an evaluation of the usefulness of the product and includes a benefit analysis to business and other operations.

Related to this is the paradox of building trust in information content quality while also conveying data uncertainties. Again, users frequently need a less-complicated answer than the highly scrubbed data provide.

As noted by an earlier group, a key discussion addressed building capacity by sharing assets and training people to find and use available resources, including online tutorials—especially important for developing countries. As reported earlier, the divide between sophisticated and unsophisticated users is a wide one as regards data access, availability, and manipulation. On the topic of scattered resources, **Jim Acker** said there are some websites that consolidate them; however, the agencies need to be mindful of customer demand for "one-stop-shopping." In support of raising awareness about satellite assets and training opportunities, **Veronica Lance** suggested that getting stories out to the public about how data are used is an effective way to spark ideas.

There was a question about whether NOAA provides a routine dataset on ocean acidity. A group at NOAA develops such a product that goes into Coral Reef Watch; however, this is not yet monitored by satellites nor routinely served, although **Veronica Lance** said they are working on algorithms to do this.

When asked about how to appropriately cite data, **Jim Acker** responded that there are instructions for this on each dataset's landing page. **Carlos Del Castillo** pointed out that users need to be aware that agencies serve out each other's data which can lead to credit confusion, e.g., NASA data might incorrectly be credited to NOAA. **Veronica Lance** mentioned that metadata helps with this by including the history of a dataset.

All-Panel Discussion Summary

At the conclusion of the fourth panel, the panelists from all four panels gathered to synthesize concepts raised throughout the day. The main point of discussion was the extent to which end-user needs are guiding product and mission development. Commercial businesses use needs analyses to assess and guide product development. **Mitch Roffer** asked whether anyone has done this, to which **Mark Eakin** and **Shelly Tomlinson** replied that NOAA has done this for Coral Reef Watch and HAB forecasting, and **Steven Pawson** replied that NASA GMAO also does to some extent. **Mark Eakin** qualified that people need to see example products first to give them a concept of what's possible, before they can give feedback on how well the product can serve their needs.

Carlos Del Castillo mentioned the best mechanism for users to get exactly what they need is by establishing a true partnership with an academic research organization during a NASA Applied Sciences Program funding call, especially where funding is the limiting factor. NASA's Early Adopters Program is another way to gauge user needs early in mission design and development process, in which users test synthetic data prior to launch—not just for PACE, but for all future missions. Engineering trade-offs made in concert with end-user needs can lead to more-efficient use of available resources, as was done by ESA in conducting a needs assessment prior to the Copernicus mission. **Christoph Aubrecht** added that international collaboration can also help with funding constraints. For example, NASA and ESA work together on joint campaigns as well as on the upcoming ESA Biomass Mission, planned to launch in 2021.

On the subject of whether user needs are identified through top-down mechanisms (i.e. data in search of users), **Christoph Aubrecht** shared that ESA strategically engages leadership teams at development banks that are developing goals and ESA advises on how Earth observations can help address these long-term goals. **Carlos Del Castillo** contrasted this with the practice at NASA, where Applied Science proposals have traditionally been led by scientists rather than end-users. **Woody Turner** responded that this is changing and that end-users are now writing proposals.

As to how users could learn about and access the plethora of available resources, **Steven Pawson** noted that products are probably underutilized due to lack of awareness. **Beth Lowell** reiterated that there are a lot of freely available, great data resources online, but that it's not always obvious where to find what one needs.

"As the medical director of a southern California marine mammal rehabilitation center, I am always in need of current data concerning domoic acid blooms in southern California waters. We have been using these pictorial data to keep abreast of the seasonal trends in domoic blooms that impact marine mammals in southern California waters. For the first time in 20 years we are able to verify domoic acid blooms in a timely fashion, that could result in moderate to severe pathologies and deaths in marine mammals in Orange County waters. This is a classic example of 'forewarned is forearmed.'…."

—Richard Evans,
The Pacific Marine Mammal Center, Laguna Beach, CA

Keynote Presentation

Paul Woods [GFW—*Chief Technology Officer*] discussed traffic in the South China Sea and pointed out that many vessels actively try to avoid detection. He noted that the global economy loses $83 billion annually to illegal fishing, overfishing, and poor fisheries management. In response to this daunting problem, Oceana, Skytruth, and Google conceived and created GFW and publically launched it in 2014. Woods described how GFW has used the Automatic Identification System (AIS) to identify ~60,000 vessels since 2012. This tool was developed to jumpstart a discussion about how to track vessels—successfully. Woods went on to describe how satellite data are applied to GFW to identify vessel type. This is important because vessels lie about their AIS identification. GFW uses machine learning to recognize patterns, allowing them to distinguish fishing vessels from non-fishing vessels, and then distinguish the types of fishing vessels, e.g., trawl, longline, or purse seine. The system was launched at the Our Ocean Conference in 2016, and already has users from 189 countries, with 32,500 registered users and 5,000 core users. Woods summarized many of the applications of GFW and its research program, and showed an example of combining Sentinel-1 satellite radar data with AIS data in Google Earth Engine to improve the ability to identify nonbroadcasting vessels—the so-called "dark fleet."

With more capabilities coming online, this is an exciting time for remote sensing. The flipside is that with increasing amounts of data available, there is an ever-increasing need to distill key information from those data and get that information to end-users.

Keynote Presentation Discussion Summary

Participants discussed the challenges of enforcing IUU regulations and whether additional assets might be integrated. **Paul Woods** suggested that suborbital assets (i.e., unpiloted aerial vehicles) could help. High-resolution images by private companies (e.g., Digital Globe) were also discussed, but there are many challenges to using these data with any frequency, and it is not fast to get an image this way. New SAR constellations will increase temporal frequency. The consensus was that the problem requires a multilayered approach: GFW can help with the big picture of the IUU problem but needs people on the water too. Additionally, sometimes the problem is not with getting the information, but moving it to the right organizations, such as law enforcement. High costs associated with targeted scenes is another area of concern. End-users with demonstrable needs must keep asking cognizant agencies and companies for these sorts of data. **Mitch Roffer** asked whether NOAA uses GFW data to study fishing effort over time, but **Paul Woods** responded that GFW gets more engagement outside of the U.S. on that issue.

With more capabilities coming online, this is an exciting time for remote sensing. The flipside is that with increasing amounts of data available, there is an ever-increasing need to distill key information from those data and get that information to end-users.

Conclusion

Stephanie Uz and **Janet Ranganathan** wrapped up the meeting with a few closing remarks and an opportunity for some final input from the participants. Both of them emphasized the need to continue the dialogue between satellite data providers and users in order to tailor products to user needs, along with intermediaries who build customizable tools for a broad target audience, offer training opportunities, and promote success stories about people already applying the data. NASA and NOAA will also coordinate efforts with other groups undertaking similar efforts, such as GEO Blue Planet.

Paul DiGiacomo noted that success stories are a useful way to connect new users, and offered the opportunity for Blue Planet to work with NASA, NOAA, and WRI in sharing stories and case studies (e.g., the Aquawatch report on water-quality-monitoring case studies). He reiterated the importance of capacity building through training and end-user engagement. **Janet Ranganathan** reminded everyone about putting information in an accessible format where the users are, as WRI plans to do with Resource Watch (launching April 2018), combined with stories that include partners sharing data-use examples.

Future discussions and trainings will address needs identified during the workshop. ■

2017 Landsat Science Team Summer Meeting Summary

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Introduction

The summer meeting of the U.S. Geological Survey (USGS)-NASA Landsat Science Team (LST) was held June 11-13, 2017, at the USGS's Earth Resources Observation and Science (EROS) Center near Sioux Falls, SD. This was the final meeting of the Second (2012-2017) LST.[1] **Frank Kelly** [EROS—*Center Director*] welcomed the attendees and expressed his thanks to the LST members for their contributions. He then introduced video-recorded messages from South Dakota's U.S. senators, **John Thune** and **Mike Rounds**, in which they acknowledged the efforts of the team in advancing the societal impacts of the Landsat Program.

LST co-chairs **Tom Loveland** [EROS—*Senior Scientist*] and **Jim Irons** [NASA's Goddard Space Flight Center (GSFC)—*Deputy Director of the Earth Sciences Division*] also thanked the LST members and the many USGS and NASA staff that have worked with the LST over the past five years, and suggested that the meeting serve as a celebration of five years of Landsat advances. They also summarized the primary meeting objectives, which were to:

- Identify priorities for future Landsat measurements; and
- review LST research and applications activities.

[1] Historically, LST members have been competitively selected to serve five-year terms; the current LST is the second such selection, with the First LST having run from 2006–2011. The competition for the Third LST is now underway and the team should be chosen by the end of 2017. **UPDATE**: The team has now been selected. See the Editorial in this issue for details.

All meeting presentations are available at *https://landsat.usgs.gov/landsat-science-team-meeting-jul-2017*.

Tim Newman [USGS's Land Remote Sensing Program—*Program Coordinator*] and **David Jarrett** [NASA Headquarters—*Earth Science Missions Program Executive*] provided the LST with an update on Landsat's programmatic status. Newman acknowledged Landsat 9 development progress, stressing the importance of communicating the value of Landsat to the new administration, dealing with shifting budget priorities, and keeping pace with rapid technological shifts in space architectures and data management services. Jarrett briefly discussed Sustainable Land Imaging (SLI) Program activities and the importance of this USGS effort in contributing to development of Landsat 10 requirements. Jarrett also discussed the need to consider all options for Landsat configurations beyond Landsat 9, and mentioned the need to consider concepts for sensor-agnostic data products and the importance of synergy between Landsat and the European Space Agency's Copernicus Sentinel-2 mission.

Frank Avila [Landsat Advisory Group (LAG)—*Vice Chair*] gave the final introductory presentation, on how the LAG provides advice to the federal government, through the Department of the Interior's National Geospatial Advisory Committee. The LAG addresses the requirements, objectives, and actions of the Landsat Program as they apply to the continued delivery of societal benefits for the nation and the global Earth observation community. He stated that the LAG is currently investigating future global land data opportunities beyond Landsat 9.

Participants at EROS during the 2017 Summer LST meeting.
Photo credit: EROS

Landsat 7 and 8 and Archive Status

Doug Daniels [EROS—*Landsat Mission Manager*] provided updates on the status of Landsat 7 and Landsat 8 mission operations. Landsat 7 is operating at a 105% duty cycle and acquiring ~470 scenes per day with a continental acquisition strategy.[2] It also provides imaging support during the Northern Hemisphere growing season, and over Africa and Central America over the full annual cycle. The Landsat 7 observatory continues to have outstanding in-orbit performance. The end of mission planning is complete and includes overlap with Landsat 9's launch readiness. As regards Landsat 8, Daniels reported that the observatory continues to exceed in-orbit performance requirements with a continental acquisition strategy that enables the collection of ~740 scenes per day. He added that Landsat 8 has nearly reached a steady state in terms of mission operations, and as of June 2017 has acquired over one million scenes.

Brian Sauer [EROS—*Landsat Sustaining Engineering Project Manager*] discussed the current state of the Landsat archive as well as progress on and achievements of the Landsat Global Archive Consolidation (LGAC) initiative. The archive currently holds in excess of seven million scenes, of which over four million have been added through the LGAC initiative. On behalf of the LST, **Curtis Woodcock** [Boston University] recognized the EROS staff with a written statement and a placard for their LGAC efforts.

Landsat Products and Collections

Brian Sauer discussed two recent Landsat product initiatives. Collection 1 of the new Landsat collection management strategy is complete. This collection—that includes scenes from the global Thematic Mapper (TM), which flew on Landsat 4 and 5; the Enhanced Thematic Mapper Plus (ETM+) on Landsat 7; and the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) on Landsat 8—is now available. He explained that the data are graded into tiers based on geolocation quality.[3] He added that data from the Multispectral Scanner (MSS), which flew on the first five Landsat missions, will be added to Collection 1 early in 2018 after data-quality analysis and processing-level investigations have been completed. The USGS is working to improve the radiometric and geometric quality of Landsat MSS data, but most MSS Collection 1 data will fall into Tier 2.

[2] In November 2013, Landsat 7 shifted to a continental acquisition strategy in which data over Antarctica, oceanic islands, Greenland, and Row 9 and above are no longer acquired. Landsat 8 acquires Row 9 and above approximately every 4 days, always acquires the island areas, and acquires Antarctica and Greenland at rates higher than before.

[3] Data classified as Tier 1 have < 12-m (~39-ft) root-mean-square error (RMSE); Tier 2 data have > 12-m RMSE. The real-time data are processed using preliminary geometry and radiometry parameters.

The second product initiative that Sauer described involves the generation of ARD, which are consistently processed to the highest scientific standards and level of processing required for direct use in monitoring and assessing landscape change. U.S. Landsat ARD were recently completed and consist of Landsat TM, ETM+, and OLI/TIRS data gridded to the Albers Equal Area projection (a common cartographic projection), formatted into 5000 x 5000-pixel tiles, and accompanied by metadata to enable further processing while also retaining the traceability of data provenance. Specific ARD measurements include top-of-atmosphere reflectance, brightness temperature, and surface reflectance; pixel quality assessment data are also included. Additional ARD details are available at *https://landsat.usgs.gov/ard*.

Ron Morfitt [EROS—*Landsat Calibration and Validation Manager*] reported that work continues on improving the geometric consistency of all Landsat data. The first three phases of an effort to improve Landsat ground control points (GCP) have been completed and applied to Collection 1 processing; the final phase is underway and will result in a global readjustment to harmonize Landsat with Sentinel-2 imagery. He added that all Landsat data will be reprocessed once a new global Sentinel-2 reference image is completed, and the results will become part of Landsat Collection 2. Collection 2 processing is expected to begin in 2018.

Landsat 9 Development Status

Del Jenstrom [GSFC—*Landsat 9 Project Manager*] presented information on the Landsat 9 development schedule for the Operational Land Imager-2 (OLI-2), being built by Ball Aerospace & Technologies Corp., and the Thermal Infrared Sensor-2 (TIRS-2), being built at GFSC. He said both OLI-2 and TIRS-2 are progressing quickly. Upgrades to TIRS-2 include increased redundancy to satisfy reliability standards, improved stray-light performance through telescope baffling, and an improved position encoder for the scene select mirror. The Landsat 9 spacecraft will be similar to Landsat 8, with the contract competitively awarded to Orbital ATK in October 2016. The target readiness for OLI-2 and TIRS-2 integration is mid-2019, with a target launch data for Landsat 9 of no earlier than December 2020. Jenstrom described how Landsat 9 will provide continuity to the multidecadal Landsat measurement record as a core component of the SLI program. Landsat 9 has a sun-synchronous orbit, 705-km (~438-mi) altitude, 98° inclination, and a 16-day global land revisit period. NASA will oversee the Landsat 9 flight segment and checkout, and the USGS will maintain the Landsat 9 ground system and handle operations.

Jim Nelson [EROS—*Landsat 9 Project Manager*] described progress toward developing the Landsat

Mission Operation Center (LMOC), Ground Network Element (GNE), and Data Processing and Archive System (DPAS) that will include Landsat 9. The LMOC handles mission planning and scheduling, command and control, health and status monitoring, orbit and altitude maintenance, and mission data management. Nelson stated that the LMOC contract was awarded to General Dynamics Mission Systems (GDMS) in June 2017, with the LMOC facility sited at GSFC in the location currently occupied by Landsat 7 mission operations. The GNE provides space-to-ground communications for the Landsat 9 observatory, and all current ground stations used by Landsat 8 will be used by Landsat 9. The DPAS provides science data ingest, storage and archiving, image assessment and product generation, and data access and distribution. Landsat 9 will build on the DPAS system developed for Landsat 8, but will expand to include multimission capabilities.

Ginger Butcher [GSFC—*Landsat Communications and Public Outreach Coordinator*] presented information on Landsat 9's three communication themes: benefits to society, the role of Landsat in the SLI program, and advances in science and technology. The benefits-to-society theme will emphasize messaging on food and agriculture economics, water quality and resource management, forest management and assessment, and land cover change. The role of Landsat in the SLI program theme will articulate the uniqueness of Landsat data, its cornerstone in global land imaging, and its ability to enable new industries. Finally, she explained that the advances in science and technology theme will highlight improved spectral coverage as a continuation of Landsat 8, advancements in temporal coverage by leveraging other commercial and international satellite assets, and investments in the future of land-imaging technology.

NASA Multi-Source Land Imaging Update

Jeff Masek [GSFC—*Landsat 9 Project Scientist*] described NASA's Multi-Source Land Imaging (MuSLI) Science Team's objectives and its relationship to the LST. The MuSLI Science Team contributes to a research program designed to advance use of multi-source remote sensing data for land monitoring. The team is managed by the NASA Land Cover/Land Use Change Program. Masek described how MuSLI Science Team members develop algorithms and prototype products that make use of multiple satellite sources and time series approaches. The primary focus of the MuSLI Science Team's efforts to date has been on Landsat and Sentinel-1 and -2 integration, and the production of regional prototype datasets that may evolve into continental- and global-scale standard products. Masek also reported that because the MuSLI and Landsat science teams share common goals, the teams will begin holding periodic joint meetings beginning in 2018.

Landsat Global Analysis Ready Data

The Landsat Program is currently scoping and developing a Landsat data access and distribution system known as Landsat global ARD. One of greatest challenges with the Landsat global ARD concept is determining which map projection is most appropriate to preserve Landsat image quality on a global scale. Conformal map projections preserve shape, whereas equal-area map projections preserve area. Landsat Collection 1 products currently use the Universal Transverse Mercator (UTM) projection as its standard, while the U.S. ARD products are based on the Albers Equal Area projection. **John Hutchinson** [EROS—*Geographer and Cartographer*] presented an overview of map projections from a cartographic perspective, and then discussed known tradeoffs and potential differences in selecting a specific map projection for Landsat global ARD. Hutchinson emphasized avoiding oversampling effects when resampling between map projections, and cautioned that a map projection that maintains image data quality is not necessarily the map projection that provides the most desirable visual display.

Future Landsat Requirements, Capabilities, and Technology

Greg Snyder [USGS Land Remote Sensing Program—*Research, Capabilities, and Analysis–Earth Observations (RCA-EO) Sponsor*] discussed the RCA-EO process for garnering a broadly sourced set of land imaging user requirements to inform Landsat 10 mission formulation. He explained that the RCA-EO database of user-driven requirements is one of several mechanisms to support technology trade space scenarios for enhanced measurement capabilities on Landsat 10. At its core, the RCA-EO database is designed around identifying measurements that will meet or exceed minimum, targeted, and/or breakthrough requirements for each Landsat thematic and societal benefit area.

Sachi Babu [NASA's Earth Science Technology Office (ESTO)—*SLI Technology Development Manager*] presented information on NASA's SLI technology development status as part of ESTO investments. The SLI-Technology (SLI-T) program's objectives are to research, develop, and demonstrate new measurement technologies that improve U.S. land-imaging capabilities while reducing the cost of future SLI measurements.

Landsat 10 and Beyond

A critical component of scoping and defining the science, measurement, and data product requirements for designing the next generation of Landsat instruments (i.e., Landsat 10 and beyond) is to gather input from Landsat subject matter experts and operational data users. During the last half of the Second LST's tenure, LST members were charged to contribute input to the "Landsat 10 and Beyond" requirements process. They were asked to provide evidence-based rationales for an enhanced measurement capabilities trade space using four core remote sensing principles: temporal frequency, spatial resolution, spectral coverage, and radiometric resolution. Each LST member provided written feedback designed specifically to garner science and application requirements to support a LST recommendation on enhanced measurement capabilities for Landsat 10 and beyond.

Christopher Crawford [EROS, ASRC Federal InuTeq—*Landsat Deputy Project Scientist*] presented a synthesis of the LST "Landsat 10 and Beyond" inputs on science and application requirements. The LST then discussed and identified a process for how this information would translate into the Second LST's recommendation on "Landsat 10 and Beyond." They came to a consensus on an order of priority for Landsat measurement needs, overwhelmingly agreeing that increasing temporal revisit frequency is the key priority, followed by higher spatial resolution, broadening spectral coverage, and improving radiometric resolution. As a final product, the Second LST will co-author a recommendation on enhanced measurement capabilities for "Landsat 10 and Beyond" that will map onto Landsat science and application themes as well as societal benefit areas.

Landsat Science Team Presentations

During the LST meeting, time was allocated for each LST principal investigator (PI) and/or co-investigator (Co-I) to give an oral presentation on their respective Landsat science topics and data use—see **Tables 1** and **2** below. Individual presenter slides can be found at the URL referenced on page 1.

Table 1. Summary of LST meeting Oral Presentations given by Landsat PIs.

LST PI Member [Affiliation]	Presentation Title
Joel McCorkel [GSFC]	Landsat Calibration/Validation (Cal/Val) with Airborne Sensors
Dennis Helder [South Dakota State University (SDSU)]	EROS Cal/Val Center of Excellence
Eric Vermote [GSFC]	A Generic Method for Retrieval and Calibration of Aerosol and Surface Reflectance Over Land: Application to Landsat 8 and Sentinel-2
Noel Gorelick [Google]	Landsat Use and Users in Google Earth Engine
Crystal Schaaf [University of Massachusetts, Boston]	An Update on the North American Landsat Albedo Product
David Roy [SDSU]	Big Data are Not Important Unless Processed Correctly
Alan Belward [European Commission's Joint Research Center]	The Landsat Program: A Unique Contribution to Our Understanding of the Global Commons
Curtis Woodcock [Boston University]	The Benefits of Lots of Observations
Jim Hipple [U.S. Department of Agriculture (USDA) Risk Management Agency (RMA)]	Lessons Learned from Integrating Landsat-Derived Field-Level Metrics into an Operational National Agricultural Data Warehouse
Dave Johnson [USDA National Agricultural Statistics Service (NASS)]	Operational Monitoring of U.S. Croplands with Landsat 8: Where Do We Stand?
Feng Goa [USDA Agricultural Research Service (ARS)]	Vegetation Index (VI) Data Cubes for Crop Phenology Mapping and Rangeland Monitoring
Martha Anderson [USDA ARS]	Evapotranspiration (ET) Data Cubes for Water Management and Agricultural Monitoring
Rick Allen [University of Idaho]	Developing and Enhancing Landsat-Derived Evapotranspiration and Surface Energy Products
Leo Lymburner [Geoscience Australia]	Gaining New Insight by Placing the Landsat Archive into the Context of Rainfall Records and Tidal Models
Patrick Hostert [Humbolt University of Berlin]	Landsat, LGAC, and Sentinel-2: Disentangling Coupled Human-Environment Systems

continued on page 25

Table 1. (cont.) Summary of LST meeting Oral Presentations given by Landsat PIs.

LST PI Member [Affiliation]	Presentation Title
Mike Wulder [Canadian Forest Service]	Integrating the Past, Present, and Future of Landsat: Continuity of Science, Applications, Monitoring, and Reporting
Randy Wynne [Virginia Tech]	Beyond Finding Change: Multitemporal Landsat for Forest Monitoring and Management
Warren Cohen [U.S. Forest Service]	A Multispectral Ensemble for Forest Disturbance Detection Using LandTrendr
Jim Vogelmann [USGS]	Monitoring Vegetation Change Using Time Series Data: Challenges and Opportunities
Robert Kennedy [Oregon State University]	Landsat's Landscape Narratives: What a Yearly Time Series Approach Has Told Us About a Changing Land Surface
John Schott [Rochester Institute of Technology]	Assessing the Ability of Current and Future Landsat Missions to Monitor Cyanobacteria Blooms Using Modeled Spectra Matching
Ted Scambos [University of Colorado]	Cryospheric Applications of Landsat: Review and Outlook

Table 2. Summary of LST meeting Oral Presentations given by Landsat CoIs.

LST Co-I Member [Affiliations]	Presentation Title
Jordan Graesser [Boston University]	Using Harmonized Landsat/Sentinel-2 Time Series to Estimate Seasonal Dynamics in Land Surface Phenology
Justin Huntington [Desert Research Institute]	Recent Advancements in Developing and Using Landsat-Derived States and Fluxes for Land and Water Decision Support
Ayse Killic [University of Nebraska]	Using the Google Earth Engine App for Residential Water Use and Preservation: Application to Monitor Reductions in Green Landscapes in Residential Areas Following Calibration for National Agriculture Imagery Program Imagery with Landsat Surface Reflectance
Joanne White [Canadian Forest Service]	Demonstrating Landsat's Capacity to Inform Forest Monitoring, Reporting, and Policy Development
Chunqiao Song [UCLA, for **Yongwei Sheng**]	Circa-2000 and Circa-2015 Global Lake Products Developed from Landsats
Nima Pahlevan [GSFC]	Landsat-Sentinel Constellation for Regular Monitoring of Global Water Quality: Current Status and Future Needs

Conclusions

The Summer 2017 LST meeting brought with it the end of the five-year terms of the Second LST. The team witnessed the launch of the Landsat Data Continuity Mission (now Landsat 8) at their first meeting in February 2013 and subsequently documented the science potential of Landsat 8 imagery. They also made many lasting contributions to the Landsat program, including studies contributing to the early planning of Landsat 9 requirements and the SLI program, the unprecedented expansion of the Landsat archive through the LGAC initiative, and contributions to improve Landsat products, such as collection management and ARD. They also provided the scientific basis for future Landsat mission requirements. In addition, the individual scientific and technical contributions of LST members were incorporated into several operational phases of Landsat processing. Landsat's value to remote sensing science and applications continues to grow, thanks—at least in part—to the LST's contributions, the Landsat program is arguably at its most stable point in its 45-year history.[4]

The next LST meeting time and location will be determined once the membership of the Third LST is finalized. ■

[4] To learn more about these achievements, please see *The Legacy of the Second Landsat Science Team* on page 22 of the "Landsat Science Team: 2017 Winter Meeting Summary" in the May–June 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 3**, p. 15-21—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/May%20June%202017%20color%20508.pdf*].

2017 GRACE Science Team Meeting Summary

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Introduction

For over 15 years, the Gravity Recovery and Climate Experiment (GRACE)[1] made precise measurements of changes in the gravity signals associated with exchange of mass between several Earth system components. GRACE exceeded its planned five-year mission by over a decade and surpassed all expectations in terms of science achievements, delivering extended data records of global mass redistribution for continued use in all Earth-science disciplines. However, the stress of operating in the harsh environment of space eventually takes its toll on even the most successful missions. As a result of batteries aging over the last few years, it became apparent that GRACE was nearing its end. In anticipation of this, the multinational mission operations team—made up of the German Space Operations Centre (GSOC), GeoForschungsZentrum (GFZ), NASA/Jet Propulsion Laboratory (JPL), the University of Texas at Austin's Center for Space Research (CSR), and industry support—came up with a plan, which called for a final GRACE science campaign in November, followed by decommissioning. Because of the tremendous success of GRACE, the GRACE Follow-On (GRACE-FO) mission was formulated, and is scheduled to launch early in 2018 to continue GRACE's gravity measurements and their significant utility across a wide range of applications.

The 2017 GRACE Science Team Meeting (STM) took place October 10-12, 2017, at CSR in Austin, TX, a few weeks before the planned final campaign was to take place. More than 100 scientists and engineers attended the meeting, which consisted of 45 oral presentations and additional posters distributed across the 7 science sessions. What follows is a summary of the content of each session.

[1] GRACE is a joint endeavor of NASA and the Deutsches Zentrum für Luft-und Raumfahrt (DLR) [German Aerospace Center].

Update: Shortly after the GRACE STM concluded, it became clear that its dual-satellite operations were no longer possible, as stable communication with one of the satellites that would be necessary for science operations could not be established and the mission would need to end before the final science campaign could be conducted. The mission operations team implemented the decommissioning of the two satellites on October 12. Over the coming years, the project will process a final data record to ensure consistency and contiguity with the first GRACE-FO products, to be available shortly after launch.

Opening Remarks and Programmatic Updates

After host **Byron Tapley** [CSR—*GRACE Principal Investigator (PI)*] welcomed the participants, he began with a formal presentation on the status of and prospects for the GRACE mission. The mission has produced 163 *Release-05* (RL05) monthly measurements of Earth's gravity field (out of a maximum possible 186). The project is currently finalizing the next data release (RL06) to be available by April 2018. Tapley highlighted the scientific accomplishments during the mission lifetime and described the project's plan for final data collection.

Several programmatic presentations came next.

Summarily, **Mona Witkowski** [NASA/Jet Propulsion Laboratory (JPL)] reviewed GRACE flight operations and satellite health. In particular, she mentioned that the spacecraft battery operations require regular monitoring and management to maximize the

Group photo of the 2017 GRACE STM attendees. **Photo credit:** Jianli Chen [CSR] satellite's lifetime. **Himanshu Save** [CSR—*GRACE Assistant Science Operations Manager*] gave an overview of the satellite's various systems' health and science operations. **Gerhard Kruizinga** [JPL] reviewed the status of GRACE Level-1 processing at JPL. **Henryk Dobslaw** [GFZ] presented plans for the next background model solution of the Atmosphere and Ocean Level-B De-Aliasing (AOD1B) Product. **Himanshu Save** [CSR], **David Wiese** [JPL], and **Christoph Dahle** [GFZ] reviewed the status of the latest Level-2 products produced by CSR, GFZ, and JPL, respectively. **Michael Jasinski** [NASA's Goddard Space Flight Center (GSFC)] presented the current status and future plans for the NASA Headquarters Applications Program. **Frank Flechtner** [GFZ—*GRACE Co-PI*] gave an overview of the current status of the GRACE-FO mission. **Michael Watkins** [JPL—*GRACE* and *GRACE-FO Science Team Lead*] elaborated on future activities of the Science Team after the end of the GRACE mission and with the beginning of GRACE-FO. **Gerhard Kruizinga** [JPL—*Science Data System (SDS) Manager*] provided insights into the current SDS activities in preparation for the GRACE-FO launch. Finally, **Felix Landerer** [JPL—*GRACE-FO Deputy Project Scientist*] concluded the project status session with a discussion on future Science Team activities and data analysis.

Science Sessions

The remainder of the meeting comprised seven science sessions, addressing the following topics:

- GRACE-FO and continuity;
- solid Earth sciences;
- analysis techniques and intercomparisons;
- multidisciplinary science;
- cryosphere;
- oceanography; and
- hydrology.

Each session included a series of invited and contributed presentations and time for questions and answers. In addition, there were posters relevant to each topic on display throughout the meeting, and informal discussions throughout the three days (e.g., during breaks). The GRACE STM program, abstracts, and the presentations are available at *http://www2.csr.utexas.edu/grace/GSTM*.

GRACE Follow-On and Continuity

The ensuing presentations in this session alluded to the expected performances of key instruments on GRACE, GRACE-FO, and future concepts for Next Generation Satellite Gravimetry Mission (NGGM) activities, including accelerometer and attitude control. Presentations also highlighted the importance of correctly accounting for temporal aliasing errors in gravity post-processing—in particular, the effects of tidal aliasing on the gravity field solutions.

Solid Earth Science

This session addressed primarily how glacial isostatic adjustment (GIA) affects the interpretation of the gravity measurements for climate applications. There is a new model that utilizes Bayesian statistics to derive uncertainties in GIA estimates.

GRACE Analysis Techniques and Intercomparisons

During this session, project representatives gave additional updates on data processing plans for GRACE Level-1 as well as AODB1 products. In particular, there were discussions about new solutions for simulating accelerometer data for the short period, when only one accelerometer was operational during the time of data collection (the other accelerometer was not operating at the time, due to low power). This session also addressed new developments in alternative GRACE gravity field solutions as provided, for example, by the University of Graz, Austria; the Groupe de Recherche de Geodesie Spatiale of the French Centre National d'Études Spatiales; the Research School of Earth Sciences at Australian National University; and GSFC. Additional presentations during this session addressed analyses of the impacts of calibration and noise in some GRACE instrument data in order to reduce errors and improve future solutions. Other presentations elaborated on various filtering approaches to improving the time-variable and static gravity field derived from GRACE data.

Multidisciplinary Science

The multidisciplinary session mainly addressed signatures of Earth's rotation, length of day, and geocenter variations in the gravity data and their relationships to changes in climate. Several presentations revisited the topic of sea-level change and evaluating short- and longer-term contributions of mass change as seen by the GRACE (and the future GRACE-FO) mission.

Cryosphere

The cryosphere session included presentations that addressed improvements in techniques for deriving ice mass trends (and accelerations) from the ice sheets, glaciers, and ice caps, and their error estimates. Several presentations explored the utility of combining data from GRACE and the Greenland GPS Network with data from the Ice, Cloud, and land Elevation Satellite (ICESat) obtained over Greenland and Antarctica to get a better estimate of the ice sheet mass balance on various temporal and spatial scales. The last presentation focused on melt signatures observed at the Totten and Moscow University Glaciers in East Antarctica.

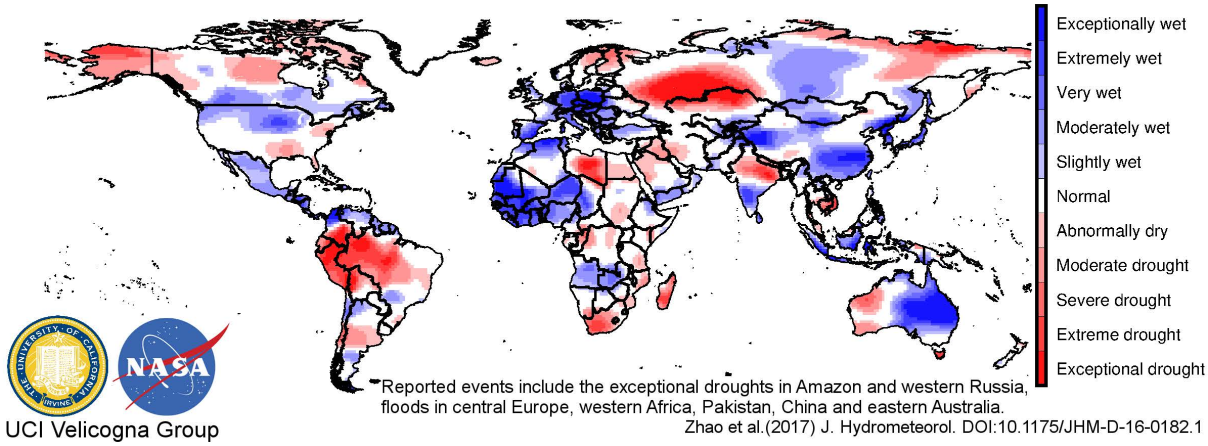

Figure. Drought severity index derived from GRACE data. The map shows areas wetter than average (blue shades) and areas dryer than average (red shades) for October 2010. **Image credit:** Isabella Velicogna, University of California, Irvine

Oceanography

The oceanography session covered gravitational regional sea-level fingerprints; barotropic and baroclinic ocean motions, tides, and currents; and implications of using GRACE data to improve knowledge of ocean circulation, generally. Presentations during this session addressed analyses of signals of the Atlantic Meridional Overturning Circulation in GRACE data and ways to use the data to better understand the past, present, and future of this important circulation pattern. Following the presentations, attendees discussed new insights into regional deep-ocean warming using a combination of GRACE and ocean altimeter data. Also discussed was the use of GRACE data to determine tide model errors and improve tide model solutions using GRACE data. In particular, at high latitudes where observations from altimetry are lacking, integrating GRACE data shows significant improvements over other approaches that do not use them.

Hydrology

The meeting concluded with a session focused on the large variety of new applications of GRACE data for hydrologic science as well as providing information for decision making in water management. The session addressed advances in hydrology applications of GRACE data products, including signal interpretation, model assimilation, hydrological trends, long-term water storage variations, and terrestrial water balance decomposition.

The session opened with an overview of the ongoing European Gravity Service for Emergency Management, which uses near-real-time gravity data to provide information on droughts and floods. There was also a presentation about a new GRACE Drought Severity Index—see **Figure**—that helps users assess the regional and global severity of ongoing droughts.

The presentations that followed described additional novel applications for flood and drought forecasting and near-real-time applications of GRACE data for flood and drought monitoring. They also focused on using a multisensor assimilation approach specifically to improve estimates of terrestrial water storage. Examples of satellite data that will be used include those from GRACE/GRACE-FO, Advanced Microwave Scanning Radiometer for EOS (AMSR-E)/AMSR-2, Soil Moisture and Ocean Salinity (SMOS), and Soil Moisture Active Passive (SMAP). There was also a discussion about the potential of using GRACE data to evaluate precipitation amounts over Earth's cold regions. While several precipitation sensors struggle to measure precipitation amounts—particularly under cold conditions—GRACE can provide valuable constraints on these estimates. Other presentations focused on the use of GRACE data to better evaluate groundwater budgets and their utility in remote areas of the world.

Conclusion

The GRACE STM provided the opportunity for a fitting tribute to all that GRACE accomplished over its 15 years in orbit, and gave a preview of future plans for GRACE-FO and beyond. The science community is preparing for extending the GRACE time series via the upcoming GRACE-FO measurements to gain more insights into water cycle variability and the physics of the Earth system, and enhancing current applications of gravity measurements. To discuss the latest findings, the next GRACE/GRACE-FO STM will be held in October 2018 at the GFZ, in Potsdam, Germany. Look for details at *http://www2.csr.utexas.edu/grace/GSTM* as the date approaches. ■

Summary of the GOFC–GOLD Twentieth-Anniversary Regional Networks Summit

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Introduction

GOFC–GOLD Twentieth Anniversary meeting participants. **Photo credit:** Agricultural University of Georgia team

Global Observation for Forest and Land Cover Dynamics (GOFC–GOLD) is a coordinated international program working to provide ongoing space-based and *in situ* observations of the land surface to support sustainable management of terrestrial resources at different scales. The GOFC–GOLD program acts as an international forum to exchange information, coordinate satellite observations, and provide a framework for and advocacy to establish long-term monitoring systems. It was established as a part of a Committee on Earth Observation Satellites (CEOS) pilot project in 1997, with a focus on global observations of forest cover. Since then, the program has expanded to include two Implementation Teams: Land Cover Characteristics and Change, and Fire Mapping and Monitoring. In addition, two working groups—Reducing Emissions from Deforestation and Forest Degradation (REDD), and Biomass Monitoring—were also formed. GOFC–GOLD activities are guided by an executive committee, primarily with support from NASA and the European Space Agency (ESA). Over the past two decades, GOFC–GOLD has facilitated the development of several *regional networks* (RNs) to coordinate and exchange information, data, technology, and methods within and between regions. The RNs represent a critical link between national agencies, user groups and the global user and producer communities, and NASA funded land-cover and land-use change (LCLUC) scientists.[1] (See section on *GOFC–GOLD Regional Networks: Current Focus and New Opportunities* on page 31 for more.)

The GOFC–GOLD program celebrated its twentieth anniversary by convening a Regional Network Summit in Tbilisi, the capital of the country Georgia, September 13-16, 2017. There were 45 people from 20 countries in attendance—including participants from Africa, Asia, South America, Eastern and Southern Europe, and the U.S. The Summit was jointly hosted by the Scientific-Research Centre of Agriculture and Agricultural University of Georgia in Tbilisi. The Summit provided an opportunity for cross-network learning and experience sharing, and included assessment of past performance and future directions for RNs. The Summit provided a venue for RN members to give presentations on their research, and facilitated lively discussions between participants, who also had the opportunity to partake of an optional field visit—see *Field Visit to the Mountain Landscapes of Mtskheta-Mtianeti* on page 34. A high-level summary of the Summit proceedings follows. Readers are directed to *http://start.org/news/start-gofc-gold-summit-in-tbilisi-looks-at-strengthening-regional-information-and-knowledge-networks* to view individual presentations.

Garik Gutman [NASA Headquarters—*LCLUC Program Manager*] welcomed the participants to the Summit and stated that the GOFC–GOLD program was instrumental in calibrating and validating NASA's Earth observation data that are used for LCLUC

[1] The most recent of these is the Caucasus Regional Network (CaucRIN), which held its kickoff meeting September 11-12, 2017—in the same location as the meeting being described here.

research, and for strengthening regional LCLUC projects. The meeting's objectives were to:

- Revisit the GOFC–GOLD strategy for strengthening regional networks, including integrating socio-economic research to address LCLUC problems effectively;
- exchange ideas and experiences across the different regional networks;
- analyze lessons learned during the two decades relating to regional networks and their sustainability; and
- discuss next steps for the regional networks, including current areas of thematic interest.

John Townshend [University of Maryland, College Park—*Former Chairman of the GOFC–GOLD Program*] congratulated the team, via a video presentation, for successfully implementing the program over the past 20 years. He noted that many of the initial protocols set forth for the GOFC–GOLD Program to develop consistent methodologies to map and monitor forests and other land-use types still remain valid today. Townshend emphasized that GOFC–GOLD needs to continue working towards developing best methods and practices relevant to its thematic areas to generate products and information that are useful for policy makers. He thanked NASA and ESA for their support of GOFC–GOLD's activities and requested their continued support.

Anthony Janetos [Boston University—*Chairman of GOFC–GOLD*] reviewed the status of the program and stated that GOFC–GOLD's primary focus over time has been on forest, land cover, fire, and biomass issues, and that the program has successfully addressed calibration, validation, and intercomparison of remote sensing products. He added that the GOFC–GOLD REDD+ Sourcebook[2] emphasizes the role of satellite remote sensing in monitoring changes in forest cover, and provides clarification on the Intergovernmental Panel on Climate Change's (IPCC) guidelines for reporting changes in forest carbon stocks at the national level. As a way forward, Janetos highlighted the need for GOFC–GOLD to address other IPCC-relevant policy issues including: climate mitigation and carbon management; systematic tracking of forest loss and gain (e.g., forest degradation and above-ground carbon retrievals); understanding the role of systematic observations of climate impacts; disentangling human-driven changes from climate-driven changes; and applications focusing on climate adaptation studies. He added that GOFC–GOLD can also contribute to monitoring and verifying Intended Nationally Determined Contributions[3] and address land-cover contributions to Sustainable Development Goals.

Cheikh Mbow [SysTem for Analysis, Research and Training (START)] stated that START has been leading GOFC–GOLD capacity-building activities since 1997. START has organized many meetings and training workshops in developing countries and has helped to build the RNs. He stressed the need to address problems relating to management of natural resources through capacity-building activities. Mbow noted that partnership enhancement awards involving GOFC–GOLD researchers from developing countries have been useful for building collaborations within developing countries. START will continue implementing the GOFC–GOLD Program objectives through interacting with the executive committee and RN researchers. He stated that START's plan will facilitate cross-network connections and strengthen GOFC–GOLD networks in the coming years.

In the following sections, Implementation Team activities are summarized, as are those of the RNs.

GOFC–GOLD Land Cover Characteristics and Change Implementation Team Activities

The Land Cover Characteristics and Change Implementation Team (LC-IT) is jointly led by **Martin Herold** [Wageningen University, Netherlands] and **Curtis Woodcock** [Boston University]. The LC-IT project office is located in Wageningen, and funded by ESA. Herold reported that the LC-IT is focused on developing and evaluating methods, guidelines, tools, and products useful for land-cover measurements and monitoring using spaceborne and *in situ* observations. The LC-IT assesses current needs and deficiencies for global and regional monitoring to support global change research, national and regional forest inventories, and international policy—i.e., by working with the United Nations Framework Convention on Climate Change (UNFCCC). The LC-IT project office has been working closely with the other GOFC–GOLD implementation Team and with RNs worldwide. Within this framework, the ESA LC-IT project office helps to strengthen the GOFC–GOLD objectives to coordinate, promote, and fulfil the GOFC–GOLD land cover implementation plan, and to support ESA-related projects and services. Currently, the LC-IT focuses on:

- Promoting monitoring of land cover as an essential climate variable to the World Meteorological Organization, UNFCCC, and Global Climate Observing System (GCOS), which contributes to the UNFCCC;

[2] REDD+ stands for Reducing Emissions from Deforestation and forest Degradation + Conservation and Sustainable Development. The GOFC–GOLD REDD+ Sourcebook can be found at *http://www.gofcgold.wur.nl/redd/sourcebook/GOFC–GOLD_Sourcebook.pdf*.

[3] Intended Nationally Determined Contributions, or INDCs, is a term used under the United Nations Framework Convention on Climate Change (UNFCC) for reductions in greenhouse gas emissions.

- contributing to the REDD+ process; in particular, by updating the GOFC–GOLD REDD Sourcebook;
- coordinating research and development of the Global Forest Observations Initiative (GFOI);
- developing training materials and e-learning tools for the World Bank Forest Carbon Partnership;
- providing support to space agencies on developing user needs and standards on global land monitoring programs; and
- promoting and developing free and open source data and tools.

Three other presentations focused on GOFC–GOLD land-cover-related themes. **Pontus Olofsson** [Boston University] described how GOFC–GOLD RNs can benefit from coordination with GFOI activities, as the latter's work is focused on developing national forest monitoring systems and associated emissions. Further, the open-source-software tools the GFOI is developing will likely benefit most RN researchers. **Sylvia Wilson** [U.S. Geological Survey] discussed SilvaCarbon, which is a U.S. contribution to GFOI activities, used to conduct forest inventories that include greenhouse gas emissions and reporting. On these topics, Wilson said that GFOI has been organizing several meetings and training in different countries and stressed that there is a stronger need to involve GOFC–GOLD networks in GFOI activities. **David Skole** [Michigan State University] suggested that GOFC should focus on building national forest monitoring systems in different countries and to provide direct technical support for REDD+ activities.

GOFC–GOLD Fire Mapping and Monitoring Implementation Team Activities

The GOFC–GOLD Fire Mapping and Monitoring Implementation Team (Fire-IT) is led by three co-chairs: **David Roy** [South Dakota State University (SDSU)], **Martin Wooster** [King's College, London], and **Jesus Ayanz** [Joint Research Center, Italy]. Roy summarized the Fire-IT's activities, which focus on refining and articulating international observational requirements for fire monitoring and related data products, as well as making the best possible use of data products from existing and future satellite observing systems for fire management, policy decision making, and global change research. The Fire-IT is currently pursuing the following activities:

- Developing and refining geostationary active fire data products;
- developing Landsat 8 and Sentinel-2 moderate-resolution, burned-area data products;
- developing Suomi National Polar-orbiting Partnership (NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) coarse-resolution, burnt-area data products;
- refining Suomi NPP/VIIRS 375-m (~1148-ft) and 750-m (~2460-ft) Level-2 (swath) active fire data products and improvement of fire-radiative-power retrievals;
- developing global wildfire information systems to provide wildfire information at local, regional, and global scales;
- agricultural fire mapping and characterization;
- harmonizing polar and geostationary fire radiative power products and integrating plume height and smoke transport information for emissions quantification;
- providing inputs on fire products useful for climate change research to the Global Observing System for Climate (GCOS) community;
- strengthening RNs and assisting them in fire-related research; and
- coordinating with international agencies to develop best practices and protocols for fire observations, including accuracy assessment, in support of producing fire products and essential climate variables.

As an example of these efforts, Roy described how the Fire-IT is collaborating with the Global Wildfire Information System (GWIS) team that is hosted by the European Commission Joint Research Center (located in Ispra, Italy) and was developed under the 2015-2016 GEO Work Program. The Fire-IT plans to hold joint meetings with GWIS staff, including GOFC–GOLD RN participants, with the next meeting scheduled to take place in November 2017 in London, U.K.[4]

GOFC–GOLD Regional Networks: Current Focus and New Opportunities

RNs are a key part of the GOFC-GOLD Program—see **Figure** and **Table** on page 32. The networks enable data providers, scientists, and operational users to articulate information requirements and improve their access to and use of Earth observations data. RNs represent a critical link between national agencies, user groups, the global user and producer communities, and NASA's LCLUC scientists.

[4] The GOFC-GOLD and GWIS fire implementation meeting took place November 20-23, 2017, in London, U.K. During the meeting, GOFC Fire-IT, regional network representatives as well as NASA-funded GWIS-GEO investigators discussed strategies to strengthen Fire-IT activities listed in the text.

Olga Krankina [Oregon State University—*Former GOFC–GOLD RN Coordinator*] presented ideas on strengthening the RNs through organizing workshops that regularly bring regional practitioners together, organizing GOFC–GOLD advanced training workshops to involve regional researchers, improving knowledge transfer, and providing guidance to RN researchers on proposal writing, useful for fund raising.

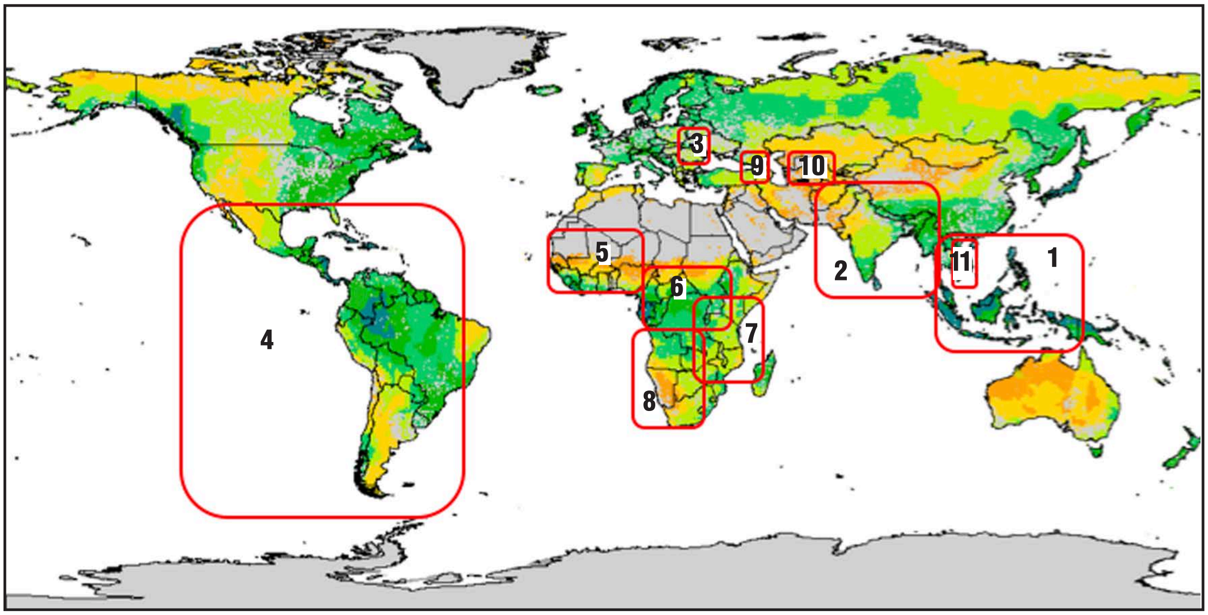

Figure 2. This map shows the currently active GOFC–GOLD RNs. 1. Southeast Asia Regional Research and Information Network (SEARRIN); 2. South Asia Regional Information Network (SARIN); 3. South Central European Regional International Network (SCERIN); 4. Red Latinoamerica de Teledeteccion e Incendios Forestales (RedLaTIF); 5. West African Regional Network (WARN); 6. Observatoire Satellital des Forets d'Afrique Central (OSFAC); 7. Miombo Network (MIOMBO); 8. Southern Africa Fire Network (SAFNET); 9. Central Asia Regional Information Network; 10. Caucasus Regional Information Network (CaucRIN); 11.Mekong Regional Information Network (MekRIN). See Table for a summary of the current and potential activities of each RN.

Table. List of GOFC RNs, their current research foci, and new opportunities. (See caption of accompanying Figure for expansion of RNs.) The information contained in this table summarizes content from presentations by a representative of each RN during the summit. The full presentations can be viewed at the URL referenced in the Introduction.

Regional Network	Current Foci	New Opportunities
Miombo	• Tracking LCLUC in the Miombo Woodlands in southern Africa • Conducting REDD+ research • Managing Miombo's ecosystem and its adaptation to climate change • Addressing human-ecosystem relationships in Miombo landscapes • Using satellite remote sensing for fire characterization	• Capacity building and training in radar remote sensing
SEARRIN	• Addressing peat-land fire related issues • Characterizing transboundary air pollution • Quantifying agricultural residue fires and their impact • Quantifying impact of biomass burning and land-atmosphere interactions • Addressing agriculture and water-resource issues in the region	• Addressing LCLUC specific to agriculture and water resources

continued on page 33

Table. (cont.) List of GOFC RNs, their current research foci, and new opportunities. (See caption of accompanying Figure for expansion of RNs.) The information contained in this table summarizes content from presentations by a representative of each RN during the summit. The full presentations can be viewed at the URL referenced in the Introduction.

Regional Network	Current Foci	New Opportunities
SARIN	• Crop-type and -area mapping, and yield forecasting • Crop water-requirements analysis • Drought assessments and early warning • Agricultural fires and pollution mitigation • LCLUC with respect to agriculture • Capacity-building and training activities with respect to remote sensing of agriculture and water resource	• Strengthening regional contacts in the region • Capacity building specific to agriculture and water resources • Evaluating, testing, and validating different LCLUC algorithms
SAFNET	• Providing satellite fire data products • Remote-sensing-based capacity building and training • Validating new satellite fire products • Supporting national and regional fire-policy development • Refining fire service—developed as a part of Monitoring for Environment and Security in Africa (MESA) • Refining Advanced Fire Information Systems (AFIS), useful for near-real-time fire monitoring	• Field validating satellite fire products • Developing fire danger rating training for the region • Enhancing MESA fire services • Engaging more academic institutions in the region
CaucRIN *	• Developing land-cover maps for the entire Caucasus region • Focusing on forest and agricultural LCLUC issues • Performing regional whole-basin LCLUC assessment for Kura River • Conducting planned meeting and training activities—including developing a web portal	*Not Applicable* (Newly formed network)
MekRIN **	• Focusing on the water, food, and energy nexus • Addressing drivers, processes and impacts linking LCLUC to dams in the Mekong region	*Not Applicable* (Newly formed network)
SCERIN	• Assessing forest changes: e.g., disturbances, biomass production, forest LCLUC, and driving forces • Assessing LCLUC and climate change • Validating and verifying data products to support current and future satellite missions • Conducting LCLUC water management (i.e., in watersheds, catchments, dams)	• Addressing LCLUC specific to land abandonment and urban expansion • Validating and verifying regional LCLUC methods and products
RedLATIF	• Characterizing fires using remote sensing • Quantifying agricultural fires and emissions • Addressing lightning fires and their impact • Assessing specific LCLUC impacts on deforestation	• Building expertise in Earth observations data processing and validation • Generating cloud-processing-based fire data products
WARN	• Satellite remote sensing of fires • Calibrating and validating fire products • Quantifying fire emissions	• Examining LCLUC relating to slash-and-burn agriculture • Performing agricultural land-use-change studies

continued on page 34

Table. (cont.) List of GOFC RNs, their current research foci, and new opportunities. (See caption of accompanying Figure for expansion of RNs.) The information contained in this table summarizes content from presentations by a representative of each RN during the summit. The full presentations can be viewed at the URL referenced in the Introduction.

Regional Network	Current Foci	New Opportunities
OSFAC	• Monitoring and evaluating forest-cover loss and changes in Central Africa • Building capacity in remote sensing and geographic information systems (GIS) • Disseminating satellite imagery in the Congo Basin • Identifying and mapping REDD+ priority areas	• Facilitating free access to remote sensing data in Central Africa • Land cover mapping for Central African countries
CARIN	• Performing water-resource management • Addressing land degradation and desertification issues • Drought mapping and monitoring • Agricultural monitoring for improved crop production	• Characterizing LCLUC with respect to lakes and high-elevation forests • Reclaiming saline soils

Field Visit to the Mountain Landscapes of Mtskheta–Mtianeti

The Scientific-Research Center of Agriculture (SRCA) organized an optional field visit for participants to see LCLUC in the mountain landscapes of the Mtskheta–Mtianeti region in Georgia. Mtskheta is the ancient capital of Georgia located 20 km (~12 mi) north of Tbilisi at the confluence of the Aragvi and Mtkvari rivers. There are Oriental hornbeam, oak, and pine forest in the lower foothills, located 500-600 m (~1640-1970 ft) above sea level [*top photo*]; and grasslands and meadows on the mountain tops, located at elevations higher than 2000 m (~6560 ft) [*bottom photo*]. The mountain landscapes are undergoing rapid changes due to urbanization and tourism. Along the way, participants visited the Research Station of SRCA, run by the Georgian Ministry of Agriculture, which focuses on research and development of native, annual, and perennial crops germplasms. A Georgian grapevine germplasm center has been in operation at SRCA since 2009, comprising 437 Georgian native grapevine varieties which are kept as collections. In addition, 150 varieties of wheat, 250 varieties of maize, and different spices, fruits, and legume germplasm varieties are preserved at the Center.

Foothills of Mtskheta, Georgia, with beech, oak, and pine forest in the lower foothills. **Photo credit:** Krishna Vadrevu

Mountain tops with grasslands and meadows in Mtskheta province, Georgia. **Photo credit:** Krishna Vadrevu

Discussion Sessions

Chris Justice [University of Maryland, College Park—*Former Co-Chair of the Fire-IT*] facilitated the meeting's discussion sessions, which are broadly summarized here. The discussion sessions focused on the priorities of the RNs, their sustainability, and the way forward. Across the RNs, the most common issue identified was sustaining funding to carry out RN activities. The GOFC–GOLD executive committee members offered guidance on joint project proposals involving the RN researchers and support for fundraising initiatives. Through START, the GOFC–GOLD team will explore new funding opportunities and communicate them to RN researchers on a regular basis. The GOFC–GOLD executive committee also suggested that RN researchers explore cost-sharing mechanisms while organizing future meetings and trainings. The RN leads asked the GOFC–GOLD executive committee to help strengthen the networks and their host institutions as regional centers of excellence on Earth observation-data processing, product development, and dissemination. RN researchers felt that designing unifying projects involving network researchers from different countries can help bring regional researchers together, which in turn can help long-term network sustainability.

During the discussion sessions, the GOFC–GOLD executive committee also shared expectations for the RNs, which include:

- Sustaining GOFC–GOLD regional activities through regional funding;
- organizing regular meetings (e.g., every two years);
- regularly providing RN researchers with contact information;
- maintaining active RN webpages with descriptions of all project activities and providing links for end-users;
- participating in GOFC–GOLD telecons; and
- providing assistance in capacity-building and training activities not only in their regions, but also through cross-network linkages.

The RN participants noted that there were sometimes parallel efforts in capacity-building activities, meetings, and training by other international organizations in their regions. To avoid duplication of effort, there is an ongoing need to coordinate different training activities with other international organizations. They also stressed the importance of effective communication to disseminate knowledge. In this context, translating GOFC–GOLD outputs to issues that people care about (e.g., land-use change impacts on food, water, livelihoods, human well-being, and the environment) was deemed highly important. Participants also encouraged using social media to share information and disseminate knowledge. This would include reviving the GOFC–GOLD main website with current information on regional projects and contacts. The ensuing discussion also highlighted the need to train regional researchers in recent technologies, to improve access to high-resolution Earth-observation data, and to involve social scientists in developing and fostering participatory approaches to address societal problems.

Conclusion

The Twentieth-Anniversary GOFC–GOLD Summit served as a forum for the exchange of ideas and information across a diverse range of RN researchers, the GOFC–GOLD executive committee, and IT members. RN researchers also emphasized the need to address policy-relevant themes to address regional problems. In addition, the Summit participants recommended increased capacity-building and training activities to advance science in different countries. ■

2017 CLARREO Science Definition Team Meeting Summary

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Introduction

The twelfth biannual meeting of the Climate Absolute Radiance and Refractivity Observatory (CLARREO) Science Definition Team (SDT) was held at the National Institute of Aerospace (NIA) in Hampton, VA, November 14-15, 2017. Over 45 participants attended the two-day meeting, coming from various institutions that included NASA Headquarters (HQ), NASA's Langley Research Center (LaRC), NASA's Goddard Space Flight Center (GSFC), NASA/Jet Propulsion Laboratory (JPL), the University of Colorado's Laboratory for Atmospheric and Space Physics (LASP), University of Wisconsin, University of Michigan, Lawrence Berkeley National Laboratory (LBNL), Science Systems and Applications, Inc. (SSAI), McGill University (Canada), University of Iowa, U.S. Geological Survey (USGS), and Imperial College London (U.K.).

Attendees at the 2017 CLARREO SDT Meeting held at the National Institute of Aerospace (NIA) in Hampton, VA. **Photo credit:** Harlen Capen [LaRC]

The meeting goals were to share and discuss updated CLARREO science results related to the Reflected Solar (RS), Infrared (IR), and Radio Occultation (RO) instruments of the full CLARREO mission; provide updates to the team on the current status of the CLARREO Pathfinder Mission; and discuss the future science landscape, taking into account the upcoming publication of the second Earth Science Decadal Survey.[1]

As has been done at each of the CLARREO science team meetings held to date, members of the SDT and CLARREO management gave presentations of progress made on their science studies and programmatic updates, respectively.

Session Topic Highlights

Provided below are highlights from a few of the presentations from the Fall 2017 meeting. Many of the presentations from the meeting can be viewed online at *https://clarreo.larc.nasa.gov/events.html*.

LaRC CLARREO/ACCESS: Pre-Formulation IR Instrument Progress

Rich Cageao [LaRC] began his presentation with a recap of the evolution of the Absolute Cross-Calibration for Earth System Science (ACCESS) IR Instrument since the 2010 CLARREO Mission Concept Review (MCR) IR instrument design. He then shared the ACCESS team's many accomplishments for FY17 toward developing and building a small-satellite, lightweight, low-cost IR instrument. Three of the most noteworthy technological achievements are highlighted below.

Successful Optical Ray-Trace Analysis of the Instrument Layout. The purpose of a ray-trace analysis is to evaluate the field-limiting and pupil-imaging characteristics of the LaRC design. In this design, the system is using a commercial interferometer scan mechanism with spaceflight heritage to provide spectral discrimination in the mid- and far-IR. **Figure 1** shows a schematic of the

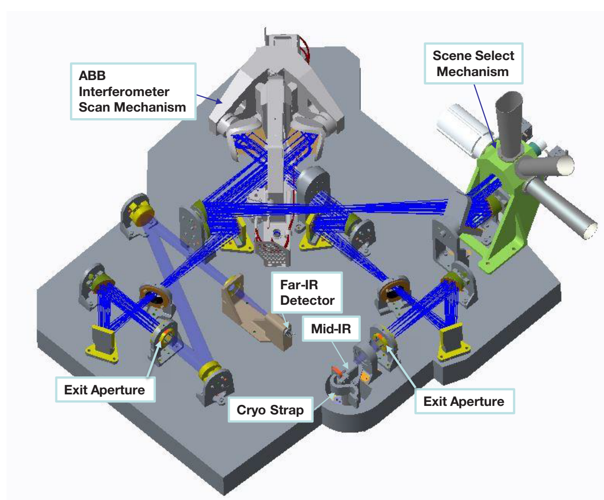


Figure 1. An *optical ray-trace analysis* shows the path in which rays take on their way through the ACCESS IR instrument to far- and mid-IR detectors. **Image credit:** LaRC

[1] The first Earth Science Decadal survey was published in 2007 and can be found at *https://www.nap.edu/catalog/11820/earth-science-and-applications-from-space-national-imperatives-for-the*. The second Earth Science Decadal Survey was released January 5, 2018. It is called *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observations* (2018), and is now available online at *https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth*.

instrument layout and the path some of the rays take as they make their way through the instrument.

Prototype Testing of the Scene Select Mechanism (SSM) Subsystem. **Figure 2** shows the Earth-scene-stabilization and calibration-source selection prototype with the goal of developing an improved design and definition, suitable for in-flight use. Testing the SSM prototype resulted in many lessons learned. Most significantly, the design for the voice coil motor used for scene stabilization provides a smooth, stable velocity ± 2° from spacecraft nadir. The motor also maintained its desired position to 1%, even in an environment with added vibration (simulating reaction-wheel- or solar-panel-induced). Further, the stepper motor, used for source selection, had consistent positioning at 90° and 180° intervals to look at the source positions of calibration blackbodies (BB), space, and a suitable Earth scene. The absolute stepper position had a preferred direction when commanded by number of steps.

Designing and Developing a Prototype High-Resolution and -Accuracy Resistance Temperature Detector (RTD) Sensor Conditioning Circuit. Using path-to-flight electronics, the team designed a high-accuracy thermal monitor for the 80 K, mid-IR, mercury-cadmium-telluride (MCT) detector to evaluate radiance detection error associated with MCT response variations. The monitor is a four-wire RTD design. Its circuit has been designed, and the schematic, layout, and fabrication completed. Testing of the circuit will continue into FY18.

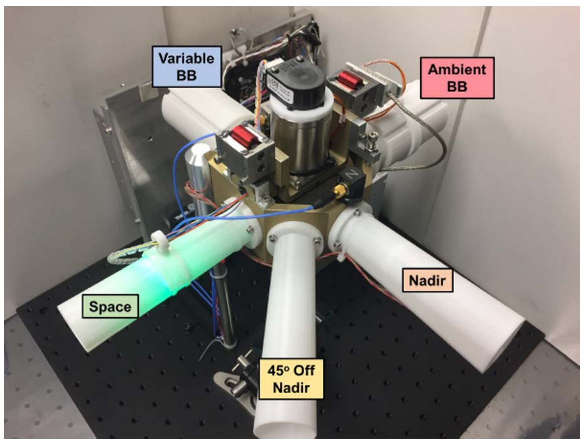
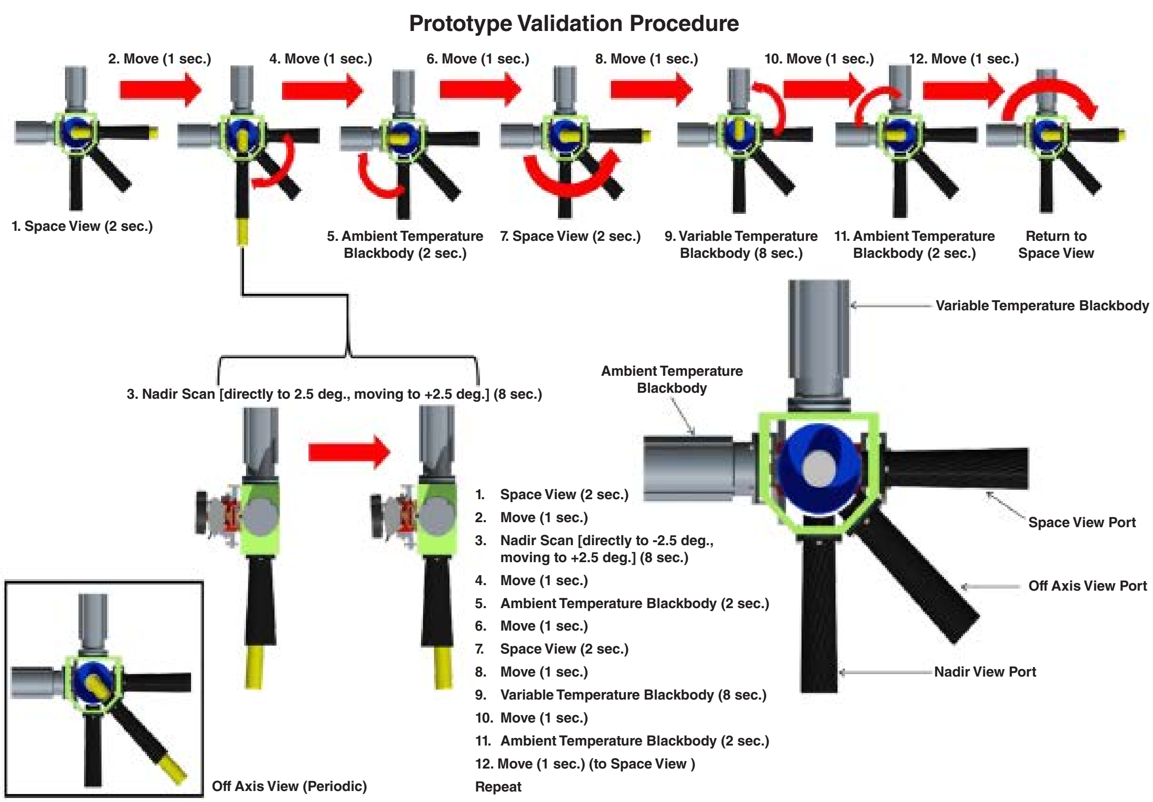


Figure 2. The Scene Select Mechanism prototype is shown [*top*] with an ambient black body (BB), a variable temperature BB, space, nadir, and off-view axis ports. This system moves according to a set prototype validation procedure, consisting of 12 steps [*bottom*], beginning and ending with a space view; the process takes 30 seconds to complete. **Image credit:** LaRC



Progress Toward a Perturbed Physics Ensemble OSSE and Optimal Strategies for its Utilization

Daniel Feldman [LBNL] provided an update to his ongoing work on a climate Observing System Simulation Experiment (OSSE). Feldman's OSSE uses climate model output as input to radiative transfer models to simulate CLARREO-like spectral measurements. Specifically, a recently developed OSSE capability can now be used to simulate CLARREO-like measurements using input from any model in the Coupled Model Intercomparison Project (CMIP) archive, including those from the two most recent versions: CMIP5 and CMIP6. Although in theory the capability is model-independent, it currently is configured to operate using a subset of models with the same convention for the vertical layering of thermodynamic and condensate information. This new OSSE capability has been successfully tested on several CMIP5 models.

Feldman stated that three 100-year shortwave (SW) reflectance runs have been completed and are available to anyone able to obtain a NASA Advanced Supercomputing (NAS) account. These completed simulations include three models that span the range of equilibrium climate sensitivities diagnosed in the CMIP5, from 2.08 to 4.0 K. These models' equilibrium climate sensitivities tend to be driven by differences in their cloud feedbacks, which are most evident in the OSSE output in the visible bands of globally averaged, spectrally resolved cloud radiative effect, as shown in **Figure 3**.

Feldman also showed a time series analysis that was previously used to determine the measurement record length needed to significantly (at a 95% confidence level) differentiate between two models' reported reflectance trends using an observational record that exhibits the instrumental noise of CLARREO. The globally-averaged results, shown in **Figure 4**, find substantial differences in model globally averaged reflectance trends between low- and high-sensitivity climate models, especially in all-sky reflectance. These results suggest that with CLARREO-like measurements, the scientific community could establish—using a 10-year record—that one of those models was significantly different from observations. The corollary is that a direct observational constraint, either excluding or accepting those models that are diagnosed with outlier values of equilibrium climate sensitivity, can be achieved with a highly-calibrated instrument with a modest record length. Both regional and global analyses highlight the utility of the information in visible and near-IR water bands to indicate model differences.

CLARREO Pathfinder Project Status

Gary Fleming [LaRC] delivered an overview of the CLARREO Pathfinder Project and its scope; its baseline mission objectives and science observations; a description of the HyperSpectral Imager for Climate Science (HySICS) instrument [a reflected solar (RS) spectrometer that will comprise the basis of the CLARREO Pathfinder payload]; and the Project's overall status since the release of the president's FY18 budget request to Congress.

Following the release of the president's FY18 budget request, the Pathfinder team received direction in late May 2017 to suspend activities related to awarding the CLARREO Pathfinder prime contract and to develop alternative work plans for FY18 Quarters 1 and 2. The impact of this direction is an approximately 11-month delay in the project's launch readiness date, now with a current best estimate of launch by Quarter 1 in CY22.

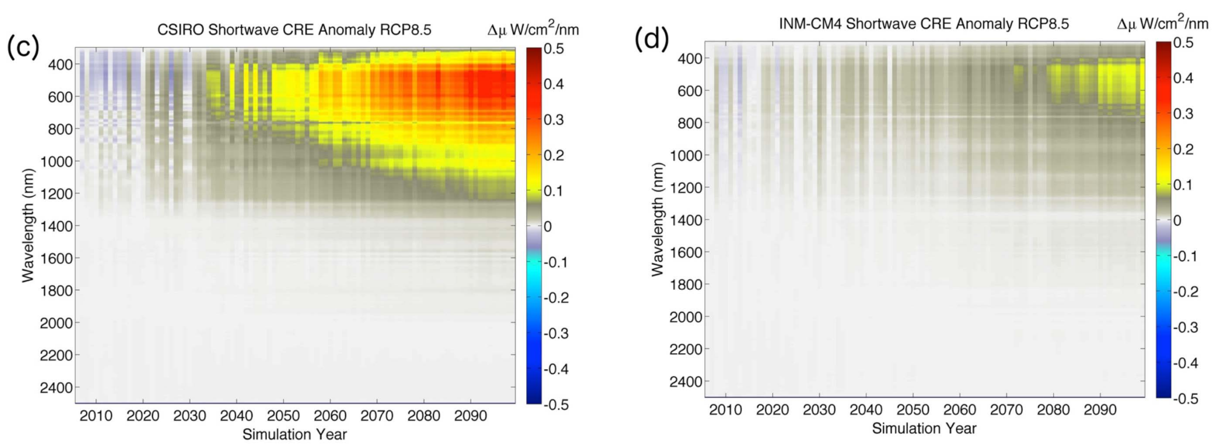


Figure 3. Shortwave spectrally resolved cloud radiative effect anomaly relative to simulations from model year 2006 for the Commonwealth Scientific and Industrial Research Organisation Mark 3.6 (CSIRO Mk3-6-0) and Russian Institute for Numerical Mathematics Climate Model Version 4 (INM-CM4) models. This comparison is intended to illustrate the large differences between the two models' shortwave cloud radiative effects and, therefore, their shortwave cloud feedbacks. The CSIRO Mk3-6-0 model's equilibrium climate sensitivity of 4.08 K is one of the largest equilibrium values in the CMIP5 archive, while the INM-CM4 model's 2.08 K equlilbrium climate sensitivity is one of the smallest in the archive. **Image credit:** LBNL

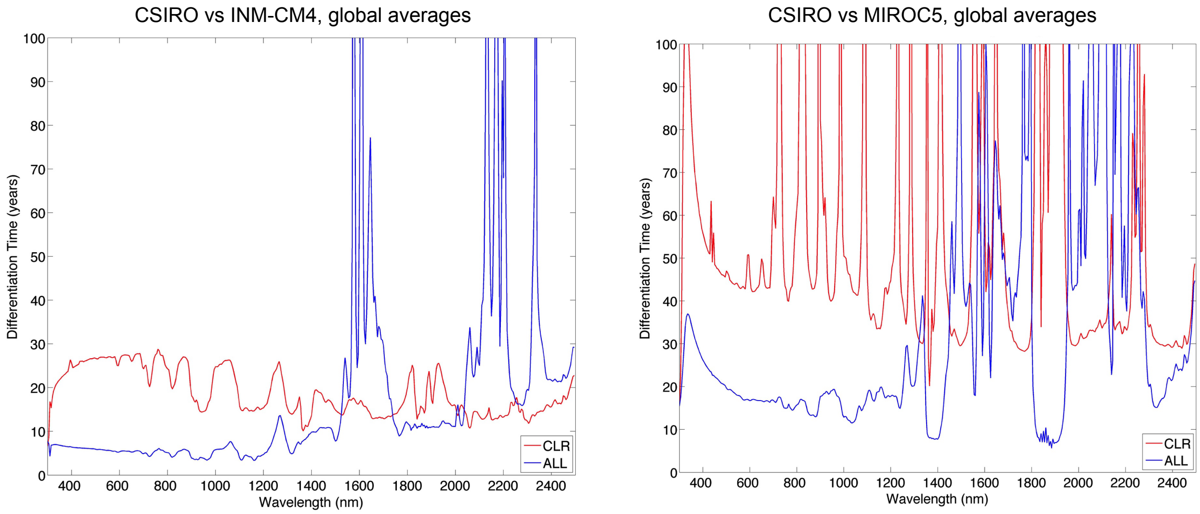


Figure 4. The left panel shows the length of time needed to distinguish between the CSIRO Mk3-6-0 and INM-CM4 models, which are the high and low equilibrium climate sensitivity (ECS) models, respectively, using clear-sky reflectance (CLR) and all-sky reflectance (ALL). The right panel is the same analysis as the left panel, but compares the CSIRO Mk3-6-0 model and the Model for Interdisciplinary Research on Climate-5 (MIROC5) model, which are the high and medium ECS models, respectively. The shorter differentiation times in the left panel compared to the right panel illustrate that less time is needed to differentiate between climate models that have climate sensitivities that differ more (4.08 K vs 2.08 K—see Figure 3) compared to climate models with ECS values that are more similar (4.08 K vs 2.72 K). **Image credit:** LBNL

On July 25-27, 2017, the CLARREO Pathfinder Project passed a combined System Requirements Review (SRR)/Mission Definition Review (MDR). Due to programmatic uncertainties, the Project did not proceed to Key Decision Point B (KDP-B) after passing their SRR/MDR. Pending new direction from NASA Headquarters, the Project anticipates conducting a delta-SRR around May 2018 as a precursor to KDP-B and an initiation of Phase-B activities. The Project has continued to operate in FY18 while the country operates under a continuing resolution. Future Pathfinder activities will be dependent upon the FY18 Congressional appropriations.

Next Steps and Moving Forward

The meeting concluded with a discussion of the next steps that the CLARREO SDT needs to take to continue moving forward with the full CLARREO mission (IR plus RS instrument) and with the CLARREO Pathfinder mission (RS only).

For the full CLARREO mission, the group discussed the need for a continued effort to advance relevant science by: publishing key journal papers on CLARREO orbit sampling and panspectral OSSE studies; conducting IR and RS intercalibration sampling; assessing risk reduction activities with CLARREO Pathfinder; advancing LaRC's IR instrument design and the University of Wisconsin's in-orbit calibration systems; aligning with the second Decadal Survey, pending direction from NASA HQ on implementation; and assessing the economic value of higher accuracy climate observation missions—most notably, CLARREO. At the close of the meeting the group declared that they would like to host discussions with members of the observation and climate modeling communities to discuss strategic planning efforts for observations needed to improve climate models.

The next CLARREO SDT Meeting is scheduled to take place in spring 2018. The location and dates are as yet to be determined. ■

Prototype Space Sensors Take Test Ride on NASA ER-2

Kate Squires, NASA's Ames Research Center, kate.k.squires@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.

Scientists recently completed test flights with prototypes of potential satellite sensors over the Western U.S. probing basic science questions about aerosols, clouds, air quality, and global ocean ecosystems.

The flight campaign called Aerosol Characterization from Polarimeter and Lidar (ACEPOL) sought to test capabilities of several proposed instruments for the Aerosol-Cloud-Ecosystem (ACE) pre-formulation study.

Aerosols are small solid or liquid particles suspended in the Earth's atmosphere, like fine dust, smoke, pollen, or soot. These particles scatter and absorb sunlight and are critical to the formation of clouds and precipitation. Scientists can analyze this scattered light using instruments like *polarimeters*, which measure the color and polarization of the scattered light, and *lidars*, which use lasers to probe the atmosphere. Together these datasets provide key information about aerosol properties including size, shape, and chemical composition—information which provides better understanding and assessment of their effects on weather, climate, and air quality.

Prior to being launched into space, airborne versions of satellite sensors typically take a test ride on NASA's ER-2 high altitude aircraft. The platform, based at NASA's Armstrong Flight Research Center, flies at altitudes of up to 70,000 ft (~21 km), and provides a vantage point and conditions similar to space. By flying these instruments on an aircraft before the expense of launching them into space, scientists and engineers can make adjustments to the hardware and data retrieval algorithms.

The ER-2 also enables scientists to observe specific events of interest like wildfires or volcanic eruptions to gain a more comprehensive collection of different types of aerosols in different conditions. The aircraft test phase in sensor development is helpful for ensuring instruments are collecting both accurate and useful data prior to the time the final version of the sensors makes its trip into space.

In addition to testing capabilities of new sensors, ACEPOL flights also provided calibration and evaluation data for NASA's Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite lidar by staging satellite underpasses as part of their flight plans. In addition to comparisons with CALIPSO, ACEPOL also contributes to the development of future satellite missions including the European Space Agency's Earth Cloud Aerosol and Radiation Explorer (EarthCare), the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) Polar Satellite–Second Generation [METOP-SG] satellites, and NASA's Multiangle Imager for Aerosols (MAIA) and Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) missions.

The cock-pit view finder in the ER-2 shows a controlled fire burning near Flagstaff, AZ on November 7, 2017. This small fire event offered the ACEPOL science team a different test environment to observe with the polarimeter and lidar instruments onboard the aircraft. **Image credit**: NASA/Stu Broce

The team completed nine flights that wrapped up in mid-November, observing targets like California's Central Valley and the Pacific Ocean, and as far east as Arizona, where the team observed smoke from controlled forest fires near Flagstaff—see photo on page 40.

The ER-2's payload included four airborne polarimeters: the Airborne Hyper-Angular Rainbow Polarimeter (AirHARP), Airborne Multi-angle SpectroPolarimetric Imager (AirMSPI), Airborne Spectropolarimeter for Planetary EXploration (AirSPEX), and Research Scanning Polarimeter (RSP). It also carried two lidar instruments: the Cloud Physics Lidar (CPL) and High Spectral Resolution Lidar-2 (HSRL-2). Each of the polarimeters used different techniques and angles to measure and record data. The instruments also differed from one another in size and power. From an engineering perspective, the ultimate goal of the ACEPOL mission was to better understand how those overall differences translate into data collection. Preliminary data from the HRSL-2 are shown in **Figures 1** and **2**.

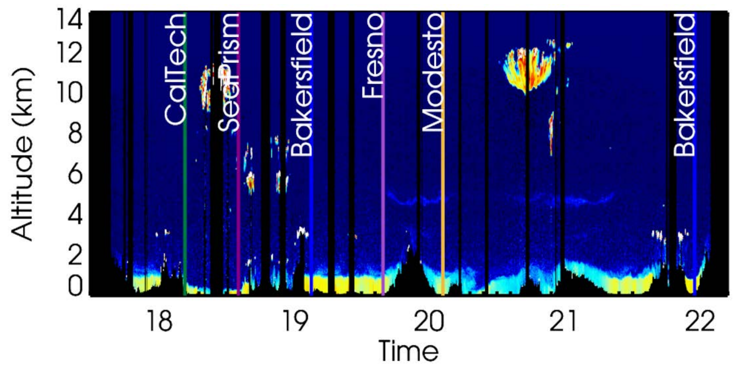


Figure 1. HSRL-2 preliminary data from the ER-2 ACEPOL flight on November 7, 2017, showing the structure of aerosol and clouds in the atmosphere along the flight track over California. Various shades indicate the amount of aerosol in the atmosphere according to HSRL-2 preliminary data. **Image credit:** NASA/Sharon Burton

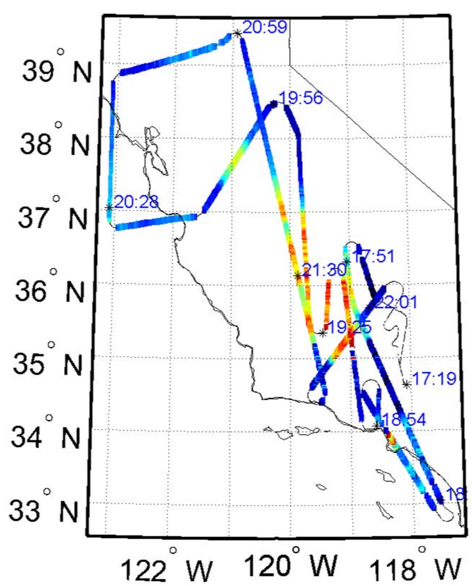


Figure 2. ER-2 flight track from the flight on November 7, 2017, for the ACEPOL campaign. Various shades indicate the amount of aerosol in the atmosphere according to HSRL-2 preliminary data. Aerosol can include smoke, pollution, dust, and sea salt. **Image credit**: NASA/Sharon Burton

The combination of the polarimeter and lidar instruments, along with ground based data from stationary air quality measurement stations provide scientists with a more complete picture of the three-dimensional distribution of aerosols in the Earth's atmosphere. Utilizing a variety of different approaches for collecting data also enables scientists to differentiate various types of aerosols (e.g., smoke, dust, pollution) and clouds (e.g., cirrus, stratus).

The ACEPOL mission involved partnership between multiple NASA centers, including Langley Research Center, Goddard Space Flight Center, the Goddard Institute for Space Studies, and the Jet Propulsion Laboratory. The mission also included international partnership with the Netherlands Institute for Space Research, which flew the AirSPEX instrument on board the ER-2 for the second time. The instrument made its maiden flight on the ER-2 in January 2016. ■

NASA-Led Study Solves a Methane Puzzle

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

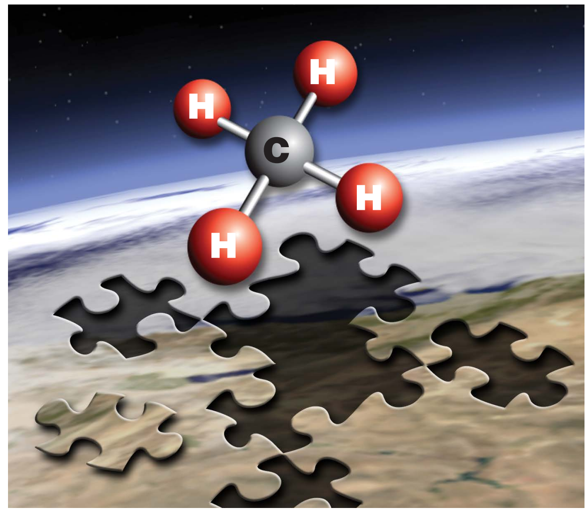
A new NASA-led study has solved a puzzle involving the recent rise in atmospheric methane, a potent greenhouse gas, with a new calculation of emissions from global fires. The new study resolves what looked like irreconcilable differences in explanations for the increase.

Methane emissions have been rising sharply since 2006. Different research teams have produced viable estimates for two known sources of the increase: emissions from the oil and gas industry, and microbial production in wet tropical environments like marshes and rice paddies. But when these estimates were added to estimates of other sources, the sum was considerably more than the observed increase. In fact, each new estimate was large enough to explain the whole increase by itself.

Scientist **John Worden** [NASA/Jet Propulsion Laboratory] and his colleagues focused on fires because they're also changing globally. The area burned each year decreased about 12% between the early 2000s and the more recent period of 2007 to 2014, according to a new study using observations by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) satellite instrument that flies on NASA's Terra and Aqua satellites. The logical assumption would be that methane emissions from fires have decreased by about the same percentage. However, using satellite measurements of methane and carbon monoxide, Worden's team found the real decrease in methane emissions was almost twice as much as that assumption would suggest.

When the research team subtracted this large decrease from the sum of all emissions, the methane budget balanced correctly, with room for both fossil fuel and wetland increases.[1] The study determined that methane emissions are increasing by about 25 teragrams a year, with total emissions currently around 550 teragrams a year. Most methane molecules in the atmosphere don't have identifying features that reveal their origin. Tracking down their sources is a detective job involving multiple lines of evidence: measurements of other gases, chemical analyses, isotopic signatures, observations of land use, and more. "A fun thing about this study was combining all this different evidence to piece this puzzle together," Worden said.

[1] This research is published in the journal *Nature Communications*. In the study, atmospheric methane concentrations are given by their weight in teragrams, which is equivalent to about 1.1 million U.S. tons—the equivalent of more than 200,000 elephants.



A new NASA-led study has solved a puzzle involving the recent rise in atmospheric methane (CH_4), a potent greenhouse gas, with a new calculation of emissions from global fires. **Image credit:** NASA

Carbon isotopes in the methane molecules are one clue. Of the three methane sources examined in the new study, emissions from fires contain the largest percentage of heavy carbon isotopes, microbial emissions have the smallest, and fossil fuel emissions are in between. Another clue is ethane, which (like methane) is a component of natural gas. An increase in atmospheric ethane indicates increasing fossil fuel sources. Fires emit carbon monoxide as well as methane, and measurements of that gas are a final clue.

Worden's team used carbon monoxide and methane data from the Measurements of Pollutants in the Troposphere (MOPITT) instrument on Terra and the Tropospheric Emission Spectrometer (TES) instrument on NASA's Aura satellite to quantify fire emissions of methane. The results show these emissions have been decreasing much more rapidly than expected.

Combining isotopic evidence from ground surface measurements with the newly calculated fire emissions, the team showed that about 17 teragrams per year of the increase is due to fossil fuels, another 12 teragrams is from wetlands or rice farming, while fires are decreasing by about 4 teragrams per year. The three numbers combine to 25 teragrams a year—the same as the observed increase.

Worden's coauthors are at the National Center for Atmospheric Research, Boulder, Colorado; and the Netherlands Institute for Space Research and University of Utrecht, both in Utrecht, the Netherlands.

NASA Study: First Direct Proof of Ozone Hole Recovery Due to Chemicals Ban

Samson Reiny, NASA's Goddard Space Flight Center, samson.k.reiny@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.

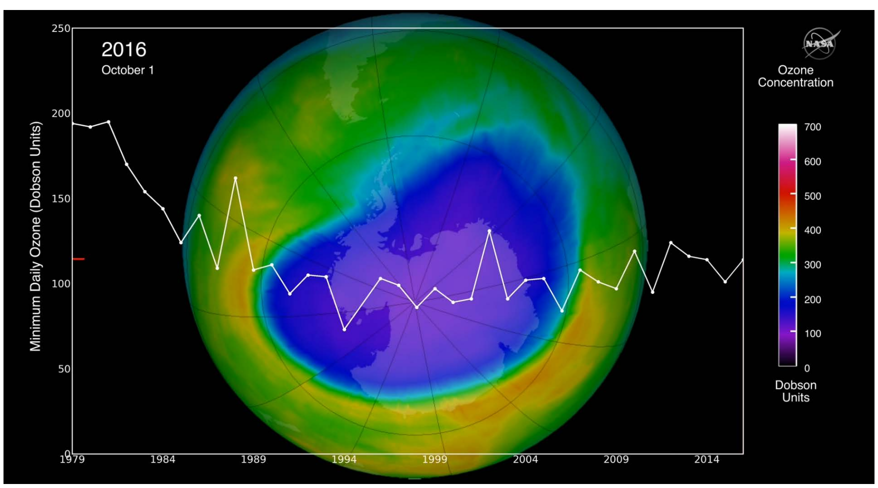
Measurements show that the decline in chlorine, resulting from an international ban on chlorine-containing manmade chemicals called chlorofluorocarbons (CFCs), has resulted in about 20% less ozone depletion during the Antarctic winter than there was in 2005—the first year that measurements of chlorine and ozone during the Antarctic winter were made by NASA's Aura satellite.[1]

"We see very clearly that chlorine from CFCs is going down in the ozone hole, and that less ozone depletion is occurring because of it," said lead author **Susan Strahan** [NASA's Goddard Space Flight Center—*Atmospheric Scientist*].

CFCs are long-lived chemical compounds that eventually rise into the stratosphere, where they are broken apart by the sun's ultraviolet radiation, releasing chlorine atoms that go on to destroy ozone molecules. Stratospheric ozone protects life on the planet by absorbing potentially harmful ultraviolet radiation that can cause skin cancer and cataracts, suppress immune systems, and damage plant life.

Past studies have used statistical analyses of changes in the ozone hole's size to argue that ozone depletion is decreasing. This study is the first to use measurements of the chemical composition inside the ozone hole to confirm that not only is ozone depletion decreasing, but that the decrease is caused by the decline in CFCs.

The Antarctic ozone hole forms during September in the Southern Hemisphere's winter as the returning sun's rays catalyze ozone destruction cycles involving chlorine and bromine that come primarily from CFCs. To determine how ozone and other chemicals have changed year to year, scientists used data from the Microwave Limb Sounder (MLS) aboard the Aura satellite, which has been making measurements continuously around the globe since mid-2004. While many satellite instruments require sunlight to measure atmospheric trace gases, MLS measures microwave emissions and, as a result, can measure trace gases over Antarctica during the key time of year: the dark southern winter, when the stratospheric weather is quiet and temperatures are low and stable.



Using measurements from NASA's Aura satellite, scientists studied chlorine within the Antarctic ozone hole over the last several years, watching as the amount slowly decreased. **Credit:** NASA's Goddard Space Flight Center/Katy Mersmann

The change in ozone levels above Antarctica from the beginning to the end of southern winter—early July to mid-September—was computed daily from MLS measurements every year from 2005 to 2016. "During this period, Antarctic temperatures are always very low, so the rate of ozone destruction depends mostly on how much chlorine there is," Strahan said. "This is when we want to measure ozone loss."

They found that ozone loss is decreasing, but they needed to know whether a decrease in CFCs was responsible. When ozone destruction is ongoing, chlorine is found in many molecular forms, most of which are not measured. But after chlorine has destroyed nearly all the available ozone, it reacts instead with methane to form hydrochloric acid, a gas measured by MLS. "By around mid-October, all the chlorine compounds are conveniently converted into one gas, so by measuring hydrochloric acid we have a good measurement of the total chlorine," Strahan said.

Two years after the discovery of the Antarctic ozone hole in 1985, nations of the world signed the Montreal Protocol on Substances that Deplete the Ozone Layer, which regulated ozone-depleting compounds. Later amendments to the Montreal Protocol completely phased out production of CFCs.

[1] This study was published in the January 4 issue of the journal *Geophysical Research Letters*.

Nitrous oxide is a long-lived gas that behaves just like CFCs in much of the stratosphere. The CFCs are declining at the surface but nitrous oxide is not. If CFCs in the stratosphere are decreasing, then over time, less chlorine should be measured for a given value of nitrous oxide. By comparing MLS measurements of hydrochloric acid and nitrous oxide each year, they determined that the total chlorine levels were declining on average by about 0.8% annually.

The 20% decrease in ozone depletion during the winter months from 2005 to 2016 as determined from MLS ozone measurements was expected. "This is very close to what our model predicts we should see for this amount of chlorine decline," Strahan said. "This gives us confidence that the decrease in ozone depletion through mid-September shown by MLS data is due to declining levels of chlorine coming from CFCs. But we're not yet seeing a clear decrease in the size of the ozone hole because that's controlled mainly by temperature after mid-September, which varies a lot from year to year."

Looking forward, the Antarctic ozone hole should continue to recover gradually as CFCs leave the atmosphere, but complete recovery will take decades. "CFCs have lifetimes from 50 to 100 years, so they linger in the atmosphere for a very long time," said study co-author **Anne Douglass** [GSFC—*Former Aura Project Scientist*]. "As far as the ozone hole being gone, we're looking at 2060 or 2080. And even then there might still be a small hole."

To read the study, visit *http://onlinelibrary.wiley.com/doi/10.1002/2017GL074830/abstract*. To watch a video about this topic and to read the original NASA news story, visit *https://www.nasa.gov/feature/goddard/2018/nasa-study-first-direct-proof-of-ozone-hole-recovery-due-to-chemicals-ban*.

Undefined Acronyms Used in Editorial and Table of Contents

ATMS	Advanced Technology Microwave Sounder
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CATS	Cloud-Aerosol Transport System
CERES	Clouds and the Earth's Radiant Energy Systems
CIRES	Cooperative Institute for Research in Environmental Sciences
DSCOVR	Deep Space Climate Observatory
EPIC	Earth Polychromatic Imaging Camera
EROS	U.S. Geological Survey's Earth Resources Observation and Sciences Center
GSFC	NASA's Goddard Space Flight Center
GST	Global Science & Technologies Inc.
GPM	Global Precipitation Measurement
JPSS-1	Joint Polar Satellite System–1
NET	No Earlier Than
NISTAR	National Institute of Standards and Technology Advanced Radiometer
NOAA	National Oceanic and Atmospheric Administration
OCO-2	Orbiting Carbon Observatory-2
QuikSCAT	Quick Scatterometer
SORCE	Solar Radiation and Climate Experiment
SMAP	Soil Moisture Active-Passive
TCTE	Total Solar Irradiance (TSI) Calibration Transfer Experiment
TES	Tropospheric Emission Spectrometer
TSIS-1	Total and Spectral Solar Irradiance Sensor–1
UMD	University of Maryland, College Park

NASA Earth Science in the News

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

[*] **New NASA Study Solves Climate Mystery, Confirms Methane Spike Tied to Oil and Gas,** January 10, *ecowatch.com*. Over the past few years, natural gas has become the primary fuel that the U.S. uses to generate electricity, displacing the long-time king of fossil fuels: coal. But new peer-reviewed research adds to the growing evidence that the shift from coal to natural gas isn't necessarily good news for the climate. A team led by scientists at NASA/Jet Propulsion Laboratory confirmed that the oil and gas industry is responsible for the largest share of the world's rising methane emissions, which are a major factor in climate change—and in the process the researchers resolved one of the mysteries that has plagued climate scientists over the past several years. Since 2006 methane emissions have been rising by about 25 teragrams every year. After reviewing satellite data, ground-level measurements, and chemical analyses of the emissions from different sources, "…the team showed that about 17 teragrams per year of the increase is due to fossil fuels, another 12 is from wetlands or rice farming, while fires are decreasing by about 4 teragrams per year," according to a January 2 NASA press release. "The three numbers combine to 25 teragrams a year—the same as the observed increase." The NASA study may help settle the science on the oil and gas industry's role in rising methane emissions.

NASA Prepares to Buy Earth Science Data from Small Satellite Constellations, January 8, *spacenews.com*. NASA plans to begin awarding sole source contracts in March to companies flying small satellite constellations as part of an Earth science data pilot program. The purchase agreements will allow NASA "…to basically buy data by the yard," said **Sandra Cauffman** [NASA Headquarters—*Deputy Director of NASA's Earth Science Division*]. In early December, NASA issued a request for information from companies currently flying constellations of at least three satellites to determine the types of data they are gathering. In response, the agency received 11 capability statements. Cauffman participated in a panel discussion on NASA and the National Oceanic and Atmospheric Administration's (NOAA's) use of commercial weather and Earth science data on January 8 (during the American Meteorological Society's Annual Meeting in Austin, TX) during which she reported that NASA plans to begin meeting with those companies to learn more about the constellations, find out how much it would cost to buy data, and what types of data licensing the firms will permit. Unlike NOAA, which is seeking to purchase weather data to share with its domestic and international partners, NASA plans initially to only share the data with researchers who can help the agency determine their value for Earth science. "If we like what we see and the data are of value, we want to go ahead after the pilot and set up a different kind of contractual mechanism for data continuity," Cauffman said.

NASA Took Pictures of the Bomb Cyclone from Space and They're Wild to See, January 9, *cnbc.com*. NASA technology has once again provided amazing photos of Mother Nature. In the first week of January, a snowy Nor'easter barreled up the U.S. East Coast. The storm was technically called a "bomb cyclone," an intimidating but scientific name given to a particular breed of storm which strengthens quickly and often includes strong winds and heavy rainfall. The storm hit Florida and the Southeast on January 3, then progressed up the East Coast, impacting South Carolina, North Carolina, Virginia, Delaware, and New Jersey on January 4. It was so large that it was clearly visible from space, and NASA used its satellites to take awe-inspiring images—see **Figure 1**.

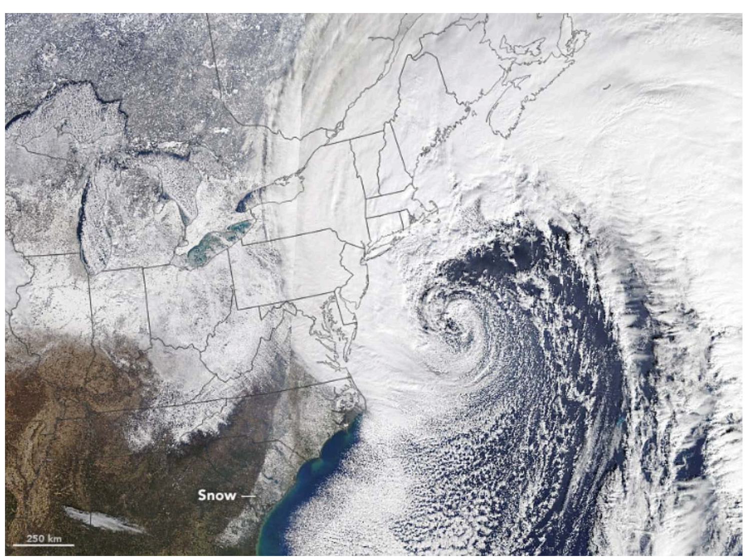


Figure 1. Millions of people along the U.S. East Coast faced snow and ice, gusty winds, power outages, travel delays, school closings, and flooding as a rapidly intensifying Nor'easter plowed northward during the first week of 2018. The Moderate Resolution Imaging Spectroradiometer (MODIS) onboard NASA's Terra satellite captured this natural-color image of the storm on January 4. **Credit**: NASA's Earth Observatory

* **The World Banned Together to Heal the Ozone Layer, and Now NASA Says It's Working,** January 5, *mashable.com*. While Earth's infamous ozone hole won't fully recover for another half-century, NASA now has its best evidence yet that this massive environmental scar is slowly beginning to heal. Using satellite data taken between 2005 and 2016, NASA scientists found that chlorine levels in the ozone hole have been decreasing by nearly 1% each year. They published their results on January 4, 2018 in the science journal *Geophysical Research Letters*. "We see very clearly that chlorine from chlorofluorocarbons, or CFCs, is going down in the ozone hole, and that less ozone depletion is occurring because of it," said the study's lead author **Susan Strahan** [NASA's Goddard Space Flight Center—*Atmospheric Scientist*]. This is the first time scientists were able to measure the chemical composition inside the ozone hole and observe a decrease in ozone depletion.

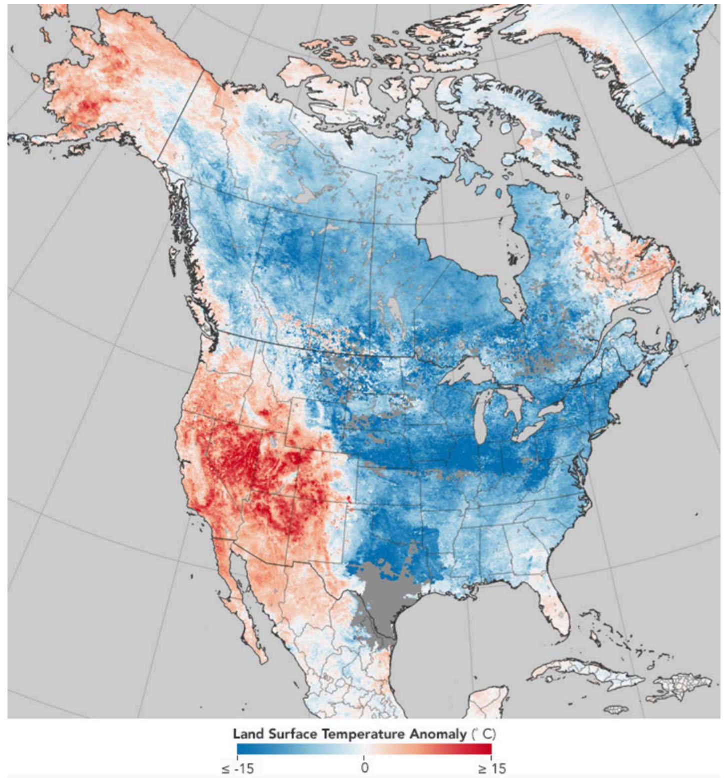


Figure 2. This temperature anomaly map is based on data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Terra satellite. It shows land surface temperatures from December 26, 2017 to January 2, 2018, compared to the 2001–2010 average for the same eight-day period. Blue shades depict areas that were colder than average; red shades depict areas hotter than average. Note that the image depicts land surface temperatures, not air temperatures. Land surface temperatures reflect how hot the surface of the Earth would feel to the touch in a particular location. **Credit:** NASA's Earth Observatory

NASA Map Shows Where Winter Weather Has Been Weirdest, January 5, *forbes.com*. Much of the eastern two-thirds of the U.S. shivered through an Arctic blast while people in the usually cold Alaskan Arctic enjoyed what they consider T-shirt temperatures. That's how the weather looked across North America between December 26, 2017, and January 2, 2018, as illustrated in a map from NASA's Earth Observatory—see **Figure 2**. The map shows land surface temperature anomalies across the continent during what was essentially the start of winter. Temperatures observed this season were measured against the 2001–2010 average for the same day period. The resulting picture is that the start to this winter has been anything but average.

NASA is Headed to Earth's Outermost Edge, January 4, *sciencenews.org*. NASA is going for the gold. Its GOLD mission (*http://gold.cs.ucf.edu*)—short for Global-scale Observations of the Limb and Disk mission—is slated for launch January 25,[1] the agency announced January 4. GOLD will study the zone where Earth's atmosphere meets outer space. Its goal is to better understand how both solar and terrestrial storms affect the ionosphere, an upper-atmosphere region crucial for radio communications. The ionosphere, which is where incoming cosmic and solar rays interact with the atmosphere to create charged particles, extends from about 75 to 1,200 km (~46 to 745 mi) above the planet's surface. From its geostationary orbit 35,000 km (~21,700 mi) high, GOLD will monitor the ionosphere's density and temperature using an instrument called an ultraviolet imaging spectrograph. Previous satellites have provided snapshots of the ionosphere, but this is the first time an instrument will keep track of changes in the layers through time, collecting data every 30 minutes.

* Please see related News story on this topic in this issue to learn more.

*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**.*

[1]**UPDATE:** GOLD successfully launched on January 25.

EOS Science Calendar

February 21–22, 2018
Landsat Science Team Meeting,
Sioux Falls, SD.
https://landsat.usgs.gov/team-meetings-agendas-and-presentations

March 19–23, 2018
2018 Sun-Climate Symposium,
Lake Arrowhead, CA.
http://lasp.colorado.edu/home/sorce/news-events/meetings/2018-scs

April 3–5, 2018
LCLUC Spring Science Team Meeting,
Gaithersburg, MD.
http://lcluc.umd.edu/meetings/2018-nasa-lcluc-spring-science-team-meeting

April 24–26, 2018
AIRS Science Team Meeting,
Pasadena, CA.
http://airs.jpl.nasa.gov/events

May 15–17, 2018
CERES Science Team Meeting,
Hampton, VA.
https://ceres.larc.nasa.gov/science-team-meetings2.php

May 16–17, 2018
CLARREO Science Definition Team Meeting,
Boulder, CO
https://clarreo.larc.nasa.gov/events.html

June 4–6, 2018
ASTER Science Team Meeting,
Tokyo, Japan.

Global Change Calendar

February 11–16, 2018
Ocean Sciences Meeting,
Portland, OR.
http://osm.agu.org/2018

April 8–13, 2018
European Geosciences Union (EGU) General Assembly,
Vienna, Austria.
https://www.egu2018.eu

May 20–24, 2018
2018 JpGU/AGU Joint Annual Meeting,
Chiba, Japan.
http://www.jpgu.org/meeting_e2018

May 28–30, 2018
Land Cover/Land Use Change International Regional Science Meeting, Quezon City, Philippines.
http://lcluc.umd.edu/meetings/land-coverland-use-changes-lcluc-and-impacts-environment-southsoutheast-asia-international

June 3–8, 2018
Asia Oceania Geosciences Society,
Honolulu, HI.
http://www.asiaoceania.org/aogs2018/public.asp?page=home.htm

July 14–22, 2018
COSPAR 2018 Assembly,
Pasadena, CA.
http://cospar2018.org

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

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