Over Thirty Years Reporting on NASA's Earth Science Program

The Earth Observer

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Editor's Corner

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The pandemic caused by the novel coronavirus disease COVID-19 continues, as well as efforts to contain the spread of the virus. Some NASA facilities have relaxed from Stage 4 of the agency response framework to Stage 3 (there are four stages, with Stage 1 being the lowest response level).[1] As mentioned in the previous editorial,[2] some consequences from reduced business activity are significant enough to be observed from space. In that sense, the COVID-19 outbreak has provided a laboratory giving scientists an unprecedented opportunity to research the many changes this unique situation has created.

For this reason, the NASA Headquarters Earth Science Division (ESD) is supporting COVID-19 impact studies through its Rapid Response and Novel Research in Earth Science (RRNES) solicitation with a rolling deadline. The agency is providing funding for selected, rapid-turnaround projects that make innovative use of satellite data and other NASA resources to address the different environmental, economic, and societal impacts of the pandemic. NASA announced in April 2020 the first RRNES projects and is continuing to evaluate new project proposals. Four of the selected proposals, as of early May 2020, are described in the News story on page 30 of this issue.

As an example of the ESD response effort, a website was developed (*so2.gsfc.nasa.gov/no2/no2_index.html*) to provide carefully and rigorously processed OMI and TROPOMI nitrogen dioxide (NO_2) datasets for world cities before, during, and after the virus activity peaks—and highlighting changes in pollution levels before and after major lockdowns. Specialized NO_2 maps and timelines for cities and regions are also provided (*airquality.gsfc.nasa.gov/news*). NO_2 is primarily emitted from the burning of fossil fuels (e.g., diesel, gasoline, coal) in automobiles and power plants. Therefore, changes in NO_2 levels can be related to changes in human activity, such as those associated with efforts to control the spread of COVID-19.

[1] For more details, see *https://nasapeople.nasa.gov/coronavirus*.
[2] See the "Editor's Corner" of the March–April 2020 issue of *The Earth Observer* [**Volume 32**, **Issue 2**, p. 1]

continued on page 2

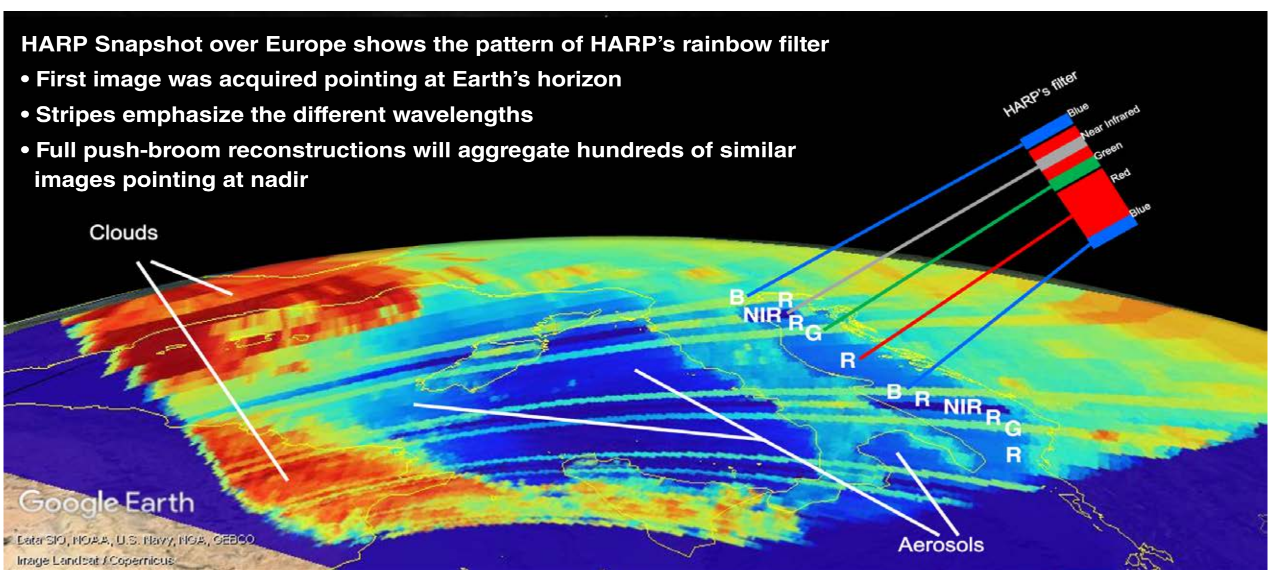


Figure 1. HARP captured its "first light" image on April 16, 2020, looking northward over southeastern Europe. The stripe-filter observations are shown for the four wavelengths. The larger 870 nm near-infrared reflectance relative to the 670 nm red band reflectance is indicative of chlorophyll-rich scenes (i.e., land vegetation and phytoplankton). The regions of high signal on the left side of the image correspond to clouds. **Image credit:** HARP CubeSat Science Team, UMBC (*esi.umbc.edu/hyper-angular-rainbow-polarimeter*)

In This Issue

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

In the November–December 2019 issue of *The Earth Observer*, we reported on the successful launch of the InVEST Hyper-Angular Rainbow Polarimeter (HARP) 3U CubeSat to the International Space Station on November 2, 2019.[3] After deployment from the ISS on February 19, 2020, and after several months of commissioning, HARP returned its "first light" images viewing the Earth's horizon on April 16, 2020—see **Figure 1** on the front cover. HARP is an imaging polarimeter (with three polarization states) developed at the University of Maryland, Baltimore County (UMBC). It has four visible and near-infrared channels. Designed for aerosol and cloud property retrievals, a unique stripe-filter detector design allows for 120 separate spectral pushbroom images, each representing different instrument view angle geometries along track. A few weeks later (May 5, 2020), HARP captured its first RGB composite of Lake Titicaca at the border of Peru and Bolivia derived from a combination of over 400 images to produce a single pushbroom composite—see **Figure 2** on page 3. The HARP CubeSat Science Operation Center (SOC) at UMBC works with the Mission Control Center at the Space Dynamics Laboratory (SDL) to determine science targets, and to monitor and control the instrument.

Last but certainly not least, effective June 8, 2020, **Karen St. Germain** became the Director of the Earth Science Division (ESD) of NASA's Science Mission Directorate. St. Germain comes to NASA after a career that has spanned NOAA, DoD, and academia. She most recently served as Deputy Assistant Administrator for Systems (DAAS) of NOAA's National Environmental Satellite, Data, and Information Service (NESDIS). In that role, she was responsible for the two major operational satellite programs that are development and acquisition collaborations with NASA—JPSS and GOES-R—as well as the COSMIC-2 mission and the Space Weather Follow-On. She also led development of next-generation capabilities to replenish and augment these systems. Prior to becoming the DAAS in 2019, St. Germain was the Director of the NESDIS Office of Systems Architecture and Advanced Planning (OSAAP), where she was involved in mission architecture planning.

St. Germain had previously been at NOAA from 2006–2011, where she worked as NOAA's lead for Suomi-NPP system performance during the mission's development. From 2011 until her return to NOAA, she worked in the Department of Defense's Space, Strategic, and Intelligence Systems (SSI) Office. St. Germain has also held research positions at the University of Massachusetts, the University of Nebraska, and the Naval Research Laboratory.

St. Germain holds a B.S. in electrical engineering from Union College (1987), a Ph.D. in Electrical Engineering from the University of Massachusetts (1993), and a M.S. degree from the National War College, National Defense University (2013).[4]

St. Germain is the successor to **Michael Freilich**, who retired from NASA in February 2019.[5] We are grateful

[3] To read more about the launch and more details about HARP, see the "Editor's Corner" of the November–December 2019 issue of *The Earth Observer* [**Volume 31**, **Issue 6**, p. 3].

[4] To learn more about Karen St. Germain, NASA's new ESD Director, visit *www.nesdis.noaa.gov/sites/default/files/StGermain_Bio_2019.pdf* and *www.youtube.com/watch?v=3U_OpShvjVU*.

[5] To learn more, see the summary of the "Symposium on Earth Science and Applications from Space with Special Guest Michael Freilich" in the March–April 2020 issue of *The Earth Observer* [**Volume 32**, **Issue 2**, pp. 4–18—*https://eospso.nasa.gov/sites/default/files/eo_pdfs/March%20April%202020%20Earth%20Observer%20Color%20508.pdf#page=4*].

to **Saundra Cauffman** and **Paula Bontempi** who served as the interim Acting Director and Deputy Director of ESD, respectively. Cauffman will return to being Deputy Director of ESD under St. Germain, while Bontempi will leave NASA at the end of the summer to become Dean of the Graduate School of Oceanography at the University of Rhode Island (URI, her Ph.D. alma mater). We extend a special note of appreciation to Bontempi for her dedicated leadership in managing the ESD ocean biology and biogeochemistry program for over 16 years and serving as Program Scientist for MODIS Terra/Aqua and several other NASA missions.

Best wishes to everyone in their new positions!

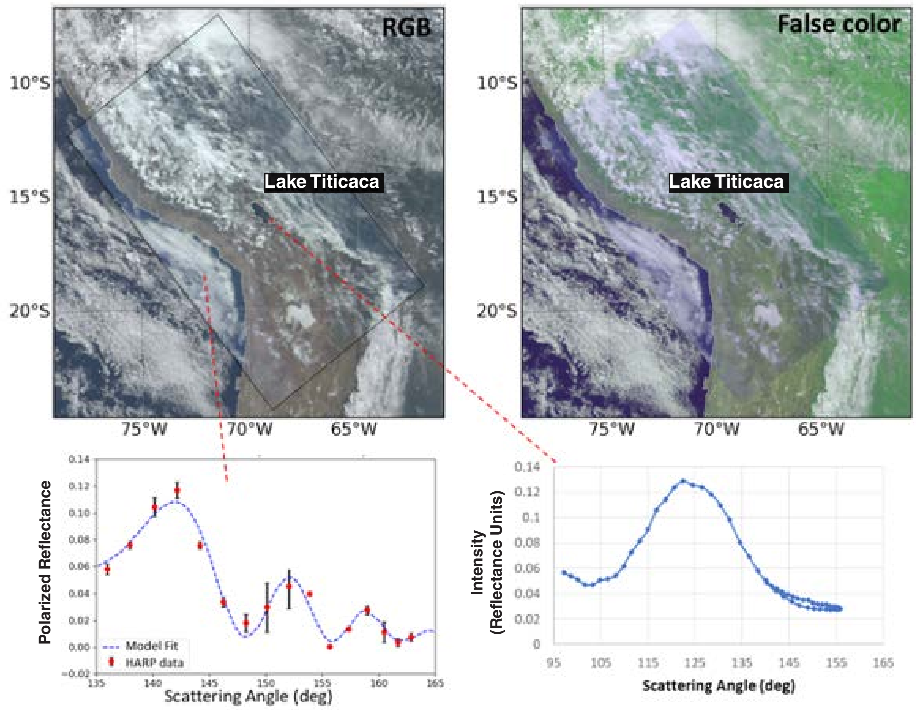


Figure 2. HARP images over the Lake Titicaca scene superimposed over GOES ABI images for "true" (Red–Green–Blue) color [*top left*] and false color [*top right*] composites showing the geolocation obtained with HARP attitude control and data processing systems. Lake Titicaca is one of the highest natural lakes in the world. It was chosen as a target since the water surface sunglint and atmospheric molecular polarization signals can be used to track and improve HARP calibration over the course of the mission. The two plots at the bottom demonstrate the hyper-angular capability of HARP to observe a single pixel from up to 60 different viewing angles. The bottom left graph shows the polarized reflectance as function of scattering angle for the cloudbow pattern over a cloudy pixel. The bottom right graph shows the intensity (in reflectance units) as function of the scattering angle, for the sunglint profile over the lake. HARP provides an unprecedented hyper-angular sampling from space (up to 60 along track viewing angles) for every pixel in the image. **Image credit:** HARP CubeSat Science Team, UMBC (*esi.umbc.edu/hyper-angular-rainbow-polarimeter*)

List of Undefined Acronyms Used in Editorial and Table of Contents

ABI	Advanced Baseline Imager
COVID-19	2019 Novel Corona Virus Disease
DoD	U.S. Department of Defense
GOES-R	Geostationary Operational Environmental Satellite System—R Series
ICESat-2	Ice, Clouds, and land Elevation Satellite—2
InVEST	In-Space Validation of Earth Science Technologies
JPSS	Joint Polar Satellite System
MODIS	Moderate Resolution Imaging Spectroradiometer
NGO	Non-Government Organizations
NOAA	National Oceanic and Atmospheric Administration
NPP	National Polar-orbiting Partnership
OMI	Ozone Monitoring Instrument
TROPOMI	TROPospheric Monitoring Instrument

Earth Day at Home with NASA

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

Earth Day celebrated its fiftieth anniversary during an unprecedented time in history as the human race fights back against the global spread of a new, or novel, coronavirus—COVID-19. While the virus brings much despair, pain, and suffering, it has also brought to light the spirit of the human race and our innate desire to connect with one another—if not in person, then virtually.

In 1968, from their vantage point in lunar orbit, the astronauts on Apollo 8 were afforded a view of Earth that no human had ever seen before. The image they saw as their spacecraft cleared the lunar horizon on its fourth orbit caught them by surprise and so captivated them that they were moved to take photographs. One of these, taken by Astronaut William Anders, became something of a global icon. Known as *Earthrise*, it shows Earth as it "rises" above the Moon's surface.[1] The first Earth Day was celebrated two years later, on April 22, 1970. **Image credit:** NASA

Introduction

Earth Day celebrated its fiftieth anniversary during an unprecedented time in history as the human race fights back against the global spread of a new, or novel, coronavirus—COVID-19. While the virus brings much despair, pain, and suffering, it has also brought to light the spirit of the human race and our innate desire to connect with one another—if not in person, then virtually. Demand for online learning, telework, and communication tools skyrocketed in late March across the U.S. and around the globe after governments enacted widespread shelter-in-place orders.

With Earth Day on the horizon and many NASA personnel continuing to do their jobs remotely,[2] the agency had to think quickly about how to participate in the usual Earth Day celebrations around the globe. Nearly overnight, NASA made the decision to shift its celebration from its traditional in-person event with a variety of hands-on activities to engage the public,[3] to one that could be carried out online, encouraging its web and social media followers to collectively appreciate the wondrous beauty of our planet and the extraordinary science that helps us understand how it all works—from the safety of home.

[1] Two posters of the iconic image that "started it all" are available for download as part of the Apollo program fiftieth anniversary resources at *https://go.nasa.gov/2ZGQSH5*.
[2] All NASA facilities are currently at Stage 3 or Stage 4 of a four-stage Response Framework. This framework is explained with a download from *https://go.nasa.gov/2VDcuk4*; the status of each center and other information about NASA's coronavirus response can be found at *https://go.nasa.gov/2IOS55z*.
[3] To read a summary of NASA's "normal" Earth Day participation, see "Hands-On with NASA: An Earth Day Experience" in the May–June 2019 issue of *The Earth Observer* [**Volume 31, Issue 3**, pp. 15–18—*https://go.nasa.gov/3epiYus*].

#EarthDayAtHome with NASA

To help connect everyone virtually this Earth Day, NASA encouraged the public to share photos and images on social media to show how they marked the fiftieth anniversary, using the hashtag #EarthDayAtHome. To help spark creativity, NASA promoted a collection of activities, videos, special programs, and other materials to help the public observe "Earth Day at Home" with an Earth Day fiftieth Anniversary Toolkit, available at *https://go.nasa.gov/2zDY8bY*. A variety of agency-wide resources are also available at *NASA at Home* (*https://go.nasa.gov/3dIisYX*) and at *NASA STEM at Home* (*https://www.nasa.gov/stem*), as well as in Spanish on *Ciencia de la NASA* (*https://ciencia.nasa.gov*).

To help connect everyone virtually this Earth Day, NASA encouraged the public to share photos and images on social media to show how they marked the fiftieth anniversary, using the hashtag #EarthDayAtHome.

In addition to these virtual collections, the agency developed content specifically for this Earth Day, including videos, online games and mobile apps, social media events, and even LEGO activities, all of which and more may be found at *https://go.nasa.gov/3cmid4h*. The remainder of this article provides a virtual tour of some online content—including several inspiring videos posted on YouTube and shared on the NASA Earth Facebook page and other NASA social media pages.

Watch and Listen

Earth's Heartbeat. The 2020 NASA Science Mission Directorate (SMD) Earth Day poster uses real science data to present a stunning illustration of how our planet's interconnected systems are its beating heart. With this year being the fiftieth anniversary of Earth Day, **Jenny Mottar** [NASA Headquarters—*SMD Art Director*] wanted to do something really special—see **Figure 1**. Watch Mottar explain her inspiration and process for creating her poster depicting the "superorganism that is Earth"[4] at *https://www.youtube.com/watch?v=rfirRx1zm_0*. The 2020 poster and others from previous years are available online at *https://science.nasa.gov/toolkits/earth-day-posters*.

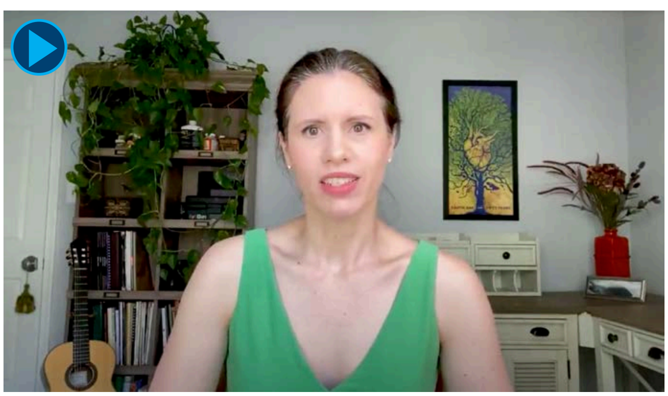


Figure 1. Jenny Mottar [*above*] explains her inspiration for the 2020 NASA Earth Day fiftieth Anniversary poster [*right*]. **Image credit**: NASA/Jenny Mottar

Special Edition. On Earth Day, **Dalia Kirschbaum** [NASA's Goddard Space Flight Center (GSFC)] hosted a "NASA Science Live: Earth Day at Home," available at *https://youtu.be/79Zjr3WRXLw*, featuring a discussion about Earth science with NASA Administrator **Jim Bridenstine**, who discussed how NASA data and technology are helping our planet, from improving agricultural productivity to mapping coral reefs to monitoring aquifers from space. In addition, **Sean Clarke** [NASA's Armstrong Flight Research Center (AFRC)—*Project Scientist for the X-57 Aircraft*] described NASA's newest electric airplane. Kirschbaum then discussed how technology

[4] In her YouTube presentation explaining the Earth Day poster, Mottar uses this quote from James Hutton, who likened the water cycle to the human circulatory system.

developed by NASA for space has been used for other applications on Earth. In this context, **Annie Meyer** [NASA's Kennedy Space Center] discussed the Orbital Syngas Commodity Augmentation Reactor (OSCAR), a system developed to reduce waste on the International Space Station (ISS) that could be applied to future space flights. **Ved Chirayath** [NASA's Ames Research Center (ARC)—*NASA NeMO-Net*[5] *Principal Investigator*] spoke about NeMO-Net, a citizen science app, which is essentially a video game that allows users to help scientists classify coral reefs (see expanded discussion of NeMO-Net on page 11). The host and participants are shown in **Figure 2**.

Figure 2. [*Right*] **Dalia Kirschbaum** [NASA's Goddard Space Flight Center] hosted a "NASA Science Live" special edition called "Earth Day at Home" on April 22, 2020. Participants included [*clockwise from upper left*] NASA Administrator **Jim Bridenstine**, **Ved Chirayath**, **Sean Clarke**, and **Annie Meyer**. **Credit:** NASA

Fifty Years of Earth Day. As the world prepared to commemorate the fiftieth anniversary of Earth Day, NASA reflected on how the continued growth of its fleet of Earth-observing satellites has sharpened our view of the planet's climate, atmosphere, land, polar regions, and ocean as shown in a video created by the NASA Scientific Visualization Studio (SVS)—see **Figure 3**. It can be viewed at *https://svs.gsfc.nasa.gov/13586*.

As the world prepared to commemorate the fiftieth anniversary of Earth Day, NASA reflected on how the continued growth of its fleet of Earth-observing satellites has sharpened our view of the planet's climate, atmosphere, land, polar regions, and ocean.

Figure 3. NASA looks back at 50 years of Earth Day. **Credit:** NASA Scientific Visualization Studio

[5] NeMO-Net stands for Neural Multi-Modal Observation and Training Network.

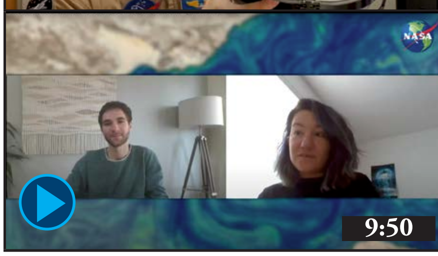
Explore Earth. NASA Earth science experts recorded a new series of short videos from their homes on a wide range of topics, from scientific advances since the first Earth Day to research expeditions in the air and on the ground. In addition, NASA astronaut **Jessica Meir** was featured in a special #EarthDayAtHome video from the ISS. The series is a featured playlist on the NASA SMD YouTube channel, available at *https://go.nasa.gov/2KQt4HW*—see **Table** for links to individual video clips.

Table. Ten videos were released via the NASA SMD YouTube channel on Earth Day.

Video Thumbnail/Length	Video Title/Presenter(s)	Direct URL
	#EarthDayAtHome with **Jessica Meir** [NASA Astronaut] on the ISS	*https://go.nasa.gov/35impQp*
	#EarthDayAtHome Plants from Space with **Martha Anderson** [U.S. Department of Agriculture, Agricultural Research Service—*Research Physical Scientist*]	*https://go.nasa.gov/2yVNRra*
	#EarthDayAtHome with Carbon Scientist **Peter Griffith** [GSFC—*Director of NASA's Carbon Cycle and Ecosystems Office*]	*https://go.nasa.gov/2KLdo8S*
	#EarthDayAtHome with Data Visualizer **Lori Perkins** [GSFC—*Acting Head of the Scientific Visualization Studio*]	*https://go.nasa.gov/2yVNWes*
	#EarthDayAtHome: Science in Ice-olation with **Tom Neumann** [GSFC—*ICESat-2 Project Scientist*] and **Kelly Brunt** [GSFC—*Assistant Research Scientist*]	*https://go.nasa.gov/2KJzzfV*
	#EarthDayAtHome with Optical Engineer **Mark Helmlinger** [NASA/Jet Propulsion Laboratory—*Remote Sensing Calibration, Characterization, and Validation Specialist*]	*https://go.nasa.gov/2yVOfpC*

table continued on next page

Table. Ten videos were released via the NASA SMD YouTube channel on Earth Day (*continued*).

Video Thumbnail/Length	Video Title/Presenter(s)	Direct URL
	#EarthDayAtHome with Earth Scientist **Michael Freilich** [Retired from NASA Headquarters—*Former Director of NASA's Earth Science Division*]	*https://go.nasa.gov/2SmremF*
	#EarthDayAtHome with Pilot **Dave Fedors** [AFRC—*Research Test Pilot*]	*https://go.nasa.gov/2VNtwNE*
	#EarthDayAtHome with Pilot **Dean Neeley** [AFRC—*Deputy Chief Pilot*]	*https://go.nasa.gov/2VOj08T*
	#EarthDayAtHome with Oceanographers **James Fox** [Oregon State University—*Postdoctoral Scholar*] and **Ivona Cetinic** [GSFC—*Research Associate*]	*https://go.nasa.gov/2yYQl7W*

Listen Up. **Jim Irons** [GSFC—*Director of GSFC's Earth Sciences Division*] gave a special virtual presentation titled "Earth Observations from Space." Irons focused on three main themes, including how NASA has monitored Earth from space for more than 50 years; the advancement of Earth system science as a result of Earth observing data and modeling; and how Earth observations from space, along with Earth system science and modeling, produce substantial societal benefits. The talk is available at *https://go.nasa.gov/35U8ujL*. The von Kármán Lecture Series from JPL produced a live public talk titled "How NASA Observes Earth from Air and Orbit," available on YouTube at *https://www.youtube.com/watch?v=DyEBF-_d7A8&feature=youtube*—see **Figure 4**.

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Figure 4. This *von Kármán Lecture Series* titled "How NASA Observes Earth from Air and Orbit," focuses on how NASA monitors global change—from orbit, as you'd expect, but also from closer to the ground, with aircraft, boats, and buoys. **Credit:** NASA

NASA Podcasts. Two podcasts produced for Earth Day examined how we learn more about our planet through instrument measurements and human observations from space. NASA's *Curious Universe* podcast produced an episode called "Only on Earth" in which Earth scientists **Douglas Morton** [GSFC—*Chief of the Biospheric Sciences Laboratory*] and **Annmarie Eldering** [NASA/Jet Propulsion Laboratory (JPL)—*Deputy Project Scientist for the Orbiting Carbon Observatory-2 (OCO-2)* and *Project Scientist for OCO-3*] explored all the ways NASA keeps an eye on our home planet, available at *https://go.nasa.gov/2V8nxTn*. Episode 141 of the *Houston We Have a Podcast* series (called "The View from Above") featured **William Stefanov** [NASA's Johnson Space Center—*Manager of the Exploration Science Office*], who shared his expertise in observing the third rock from the Sun. The episode is available at *https://go.nasa.gov/2X80t7W*.

The Best View. NASA astronauts inarguably get the best human view of our planet. For Earth Day, and in conjunction with the twentieth anniversary of the ISS in 2020, the popular "Down to Earth" video series featured astronauts talking about what it's like to see Earth from space in a special Earth Day video at *https://go.nasa.gov/2TIZJUS*—see **Figure 5**. Also on Earth Day, NASA Astronaut **Chris Cassidy**, who arrived at the ISS on April 9, 2020, answered questions from social media users in a live Q&A on NASA TV—see **Figure 6**—now available at *https://go.nasa.gov/3gs1PlE*.

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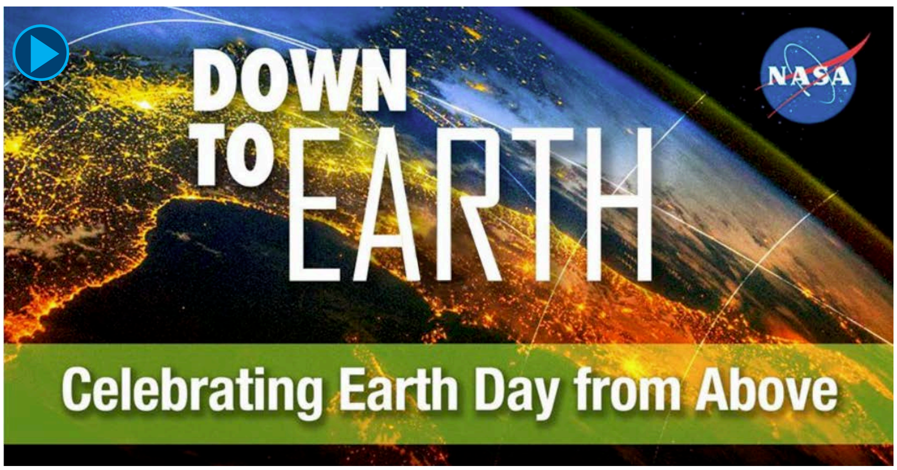

Figure 5. NASA and international astronauts recounted their experiences of Earth during their time working and living on the ISS. **Credit:** NASA

Figure 6. Aboard the International Space Station, Expedition 63 Commander **Chris Cassidy** [NASA Astronaut] discussed the view of Earth from orbit and other issues related to the fiftieth anniversary of Earth Day during a downlink conversation April 22 with ABC News. Cassidy also took the opportunity to answer questions about Earth Day for NASA's social media sites during the in-flight event. **Credit:** NASA

NASA ScienceCasts. Earth-observing instruments on the ISS, along with photographs from crew members, serve to keep a multifunctional eye on our home planet. Watch "Keeping an Eye on Earth" at *https://go.nasa.gov/2ZGs9mj*—see **Figure 7**.

Earth-observing instruments on the ISS, along with photographs from crew members, serve to keep a multifunctional eye on our home planet.

Figure 7. This video shows how NASA studies Earth and how Earth's climate is the product of many rich and complex systems. **Credit:** NASA

Tumblr Answer Time. In collaboration with Tumblr, **Sandra Cauffman** [NASA Headquarters—*Acting Director of the Earth Science Division*] and **Thomas Zurbuchen** [NASA Headquarters—*Associate Administrator for NASA's Science Mission Directorate*] answered questions submitted by the public via social media—see **Figure 8**. These short videos can be watched at *https://go.nasa.gov/2WapMok*.

Figure 8. In these short video responses, one Tumblr user asked **Sandra Cauffman**, "What is it like to be a NASA Earth Scientist?" and "Were you really good in your studies, when you were a young teenager?" Other Tumblr users asked **Thomas Zurbuchen**, "What are the different fields of Earth Science? Are they related to each other?" and "What's your favorite geological feature to view from space?" **Credit:** NASA

The GLOBE Program celebrated its twenty-fifth anniversary on Earth Day 2020 with a virtual video celebration.

The GLOBE Program Celebrates 25 Years. The GLOBE Program[6] celebrated its twenty-fifth anniversary on Earth Day 2020 with a virtual video celebration. The celebration includes five videos that are available to watch at *https://go.nasa.gov/3fXZL4R*. To see how other GLOBE countries celebrated, visit *https://go.nasa.gov/2M5vAem*. Additionally, GLOBE community members posted Earth Day greetings or congratulatory messages commemorating the anniversary on a common online wall—a "padlet," or message board. To read these inspiring messages, visit *https://go.nasa.gov/2Bav7Fz*.

[6] The Global Learning and Observations to Benefit the Environment (GLOBE) Program is an international science and education program that provides students and the public worldwide with the opportunity to participate in data collection and the scientific process, and contribute meaningfully to our understanding of the Earth system and global environment. For more information, visit *https://www.globe.gov*.

Bring the World to Your World

Despite not being able to have the traditional in-person gathering, NASA personnel still provided an abundance of hands-on activities for this virtual Earth Day celebration. By participating in these activities, "attendees" could (and still can!) take quizzes, delve into activities that give a taste of what Earth science research is all about, learn how weather- and climate-related decisions are made, view NASA Earth science images and posters, and more. A few of these activities are summarized here. Since many of these activities are still available online, they are described as ongoing possibilities; others were real-time events, and so are closed for further activity, although the sites may still be visited.

Earth Day at Home Webquest. Participants go on a "NASA Earth Science Webquest" at *https://climate.nasa.gov/Earth-Day-2020* to see how NASA helps study and protect the land, air, water, and ice. A fun, interactive quiz then shows how much has been learned.

Map Real Coral Reefs. NASA classifies and maps three-dimensional (3D) images of real coral reefs, and participants can use their mobile devices to help, with the new NeMO-Net app (*http://nemonet.info*). The images from satellites are made using special "fluid lens" cameras for clear pictures without the distortion of moving water. As players at all levels map the coral, they help the supercomputer at NASA's Ames Research Center "learn" how to classify coral on its own.

Hit the Bricks. On Earth Day, LEGO builders around the world had a special #LetsBuildTogether challenge developed with NASA—see **Figure 9**. As this challenge had a finite closure date, no further activity is supported. However, participants interested in other LEGO-related activities can learn how to make a 3D model of precipitation from Hurricane Irma at *https://go.nasa.gov/3c3YBlb* and how to make a model of the Global Precipitation Measurement (GPM) Core Observatory satellite at *https://go.nasa.gov/36AfLpf*. Even more, participants can learn about how NASA measures rain, snow, and other forms of precipitation on the GPM Education Page, here *https://gpm.nasa.gov/education*.

Despite not being able to have the traditional in-person gathering, NASA personnel still provided an abundance of hands-on activities for this virtual Earth Day celebration. By participating in these activities, "attendees" could (and still can!) take quizzes, delve into activities that give a taste of what Earth science research is all about, learn how weather and climate-related decisions are made, view NASA Earth science images and posters, and more.

Figure 9. Shared on the NASA Earth Facebook page, sisters Annie, 11, and Lucy, 6, show their love for Earth as they participated in the LEGO Earth Day #LetsBuildTogether challenge developed by LEGO with NASA. **Photo credit:** Patrick Lynch

Make Your Own Worldview GIF. Over 20 years of satellite views of our home planet are found in NASA's online data archive. Participants can create their own Earth Day snapshots or animated GIFs with the NASA Worldview data visualization app at *https://worldview.earthdata.nasa.gov*. A special Earth Day gallery of images from this global archive of hurricanes forming, wildfires spreading, icebergs drifting, and more is available for inspiration along with a tutorial to help you create personal Earth Day images at *https://go.nasa.gov/30ElR7c*.

The success of Earth Day 2020 is an excellent example of NASA teamwork.

Terrestrial Tournament. This year the only March Madness was caused by COVID-19, but those longing to fill out a bracket could participate in NASA's Earth Observatory Tournament–Earth, which asked people to vote on their favorite Earth images in elimination brackets. The winner—"Ocean Sand, Bahamas"—was announced on April 29, capping the twentieth anniversary year for the Earth Observatory—see **Figure 10**. To view the final bracket, visit *https://earthobservatory.nasa.gov/tournament-earth/results*. As this activity had a finite closure date, only the results are shown at the site, and no further activity is supported.

Earth on Earth Day. New posters from JPL showed what Earth looked like from space on Earth Day—see **Figure 11**. Another poster provides a more-abstract image of our atmosphere. Downloadable posters and wallpaper for computers and phones are available at *https://science.nasa.gov/earth-science/documents*. Scroll down toward the bottom of the page to view the posters.

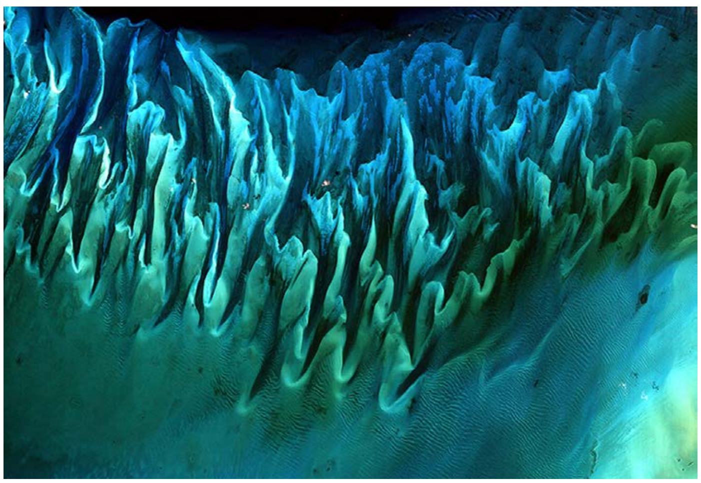

Figure 10. This image—titled "Ocean Sand, Bahamas"—is the 2020 winner of NASA's Earth Observatory Tournament–Earth, which asked people to vote on their favorite Earth images in elimination brackets. While the image may resemble a new-age painting straight out of an art gallery, it is actually a satellite image of sands and seaweed in the Bahamas. The image was taken by the Enhanced Thematic Mapper Plus (ETM+) instrument onboard the Landsat 7 satellite. Tides and ocean currents in the Bahamas sculpted the sand and seaweed beds into multicolored, fluted patterns in much the same way that winds sculpt vast sand dunes in the Sahara Desert. **Credit:** Serge Andrefouet [University of South Florida], NASA Earth Observatory

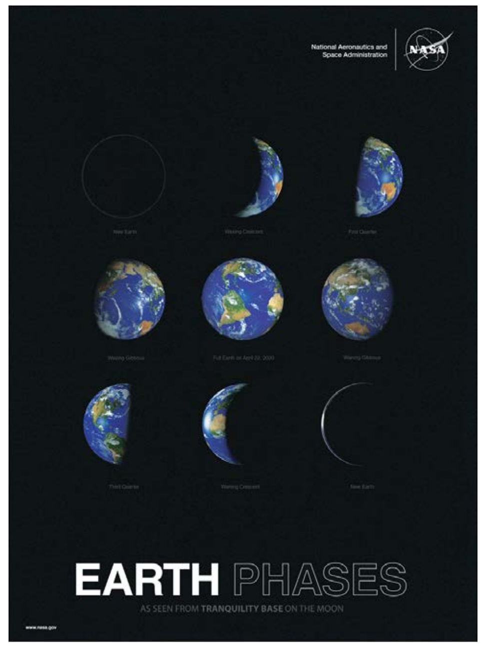

Figure 11. Our planet's phases wax and wane—just as the Moon's phases do—but in reverse order. Unlike the Moon, which always shows the same face to Earth, from space our planet clearly spins on its axis every day. Shifting the perspective between planets and their moons, this poster captures those phases as they would be seen from the Moon, including the full Earth as it appeared on April 22, 2020. **Credit:** NASA

Conclusion

The success of Earth Day 2020 is an excellent example of NASA teamwork. Even with the ongoing COVID-19 quarantine necessitating telework for most employees, in less than a month NASA moved from planning for its traditional in-person event to implementing a suite of online activities.

On this fiftieth anniversary of Earth Day, we were reminded of just how connected our species is—with each other and with our home planet—and that our daily actions matter, including those we make that impact public health as well as the environment.

To keep up with the latest Earth science news from NASA via social media, follow *@NASAEarth* on Twitter at *https://twitter.com/NASAEarth,* on Instagram at *https://www.instagram.com/nasaearth*, and on Facebook at *Facebook.com/NASAEarth*. ■

Summary of the 2019 Ocean Surface Topography Science Team Meeting

Joshua Willis, NASA/Jet Propulsion Laboratory, joshua.k.willis@jpl.nasa.gov

Introduction

The 2019 Ocean Surface Topography (OST) Science Team Meeting (STM) was held in Chicago, IL, October 21-25, 2019. This year's meeting lasted a full week and included special sessions on the Future of Altimetry (chaired by OST project scientists) and splinter sessions on Coastal Altimetry and the Chinese CFOSAT.[1]

The primary objectives of the OST STM were to address specific technical issues on the Ocean Topography Experiment (TOPEX)/Poseidon–Jason series of missions,[2] including algorithm and model improvement, calibration/validation (cal/val) activities, merging TOPEX–Jason data with those from other altimetric satellites, and preparing for future OST missions.

In terms of agenda for the OST STM, the meeting began with an opening plenary session, followed by a series of splinter sessions and a closing plenary session. The splinter session topics included:

- Application Development for Operations;
- CFOSAT;
- Coastal Altimetry;
- Instrument Processing: Measurement and Retracking;
- Instrument Processing: Propagation, Wind Speed, and Sea State Bias;
- Outreach, Education, and Altimetric Data Services;
- Precise Orbit Determination;
- Quantifying Errors and Uncertainties in Altimetry Data;
- Regional and Global Calibration/Validation for Assembling a Climate Data Record;
- Science Results, which covered:
    - Climate Data Records for Understanding the Causes of Global and Regional Sea Level Variability and Change;
    - Large-Scale Ocean Circulation, Variability, and Change;
    - Mesoscale and Sub-Mesoscale Oceanography; and
    - Altimetry for Cryosphere and Hydrology.
- The Geoid, Mean Sea Surfaces, and Mean Dynamic Topography;
- Tides, Internal Tides, and High-Frequency Processes; and
- Advances in Coastal Altimetry: Measurement Techniques, Science Applications, and Synergy with *In Situ* Observations and Models.

This report begins with an overview of the status of current and planned OST missions, followed by a brief summary of the OST STM itself. The full report on the meeting from the Ocean Surface Topography Science Team (OSTST) is available for download from *https://go.nasa.gov/2A2hiIm*, and all of the presentations from the plenary, splinter, and poster sessions are available at *https://go.nasa.gov/2LONFgi* (choose 2019 Ocean Surface Topography Science Team, and click "OK").

Status Report on Ocean Surface Topography Missions

This section reports on the status of several current and planned OST-related satellite missions.

Jason-3

Jason-3 continues the 28-year reference series of measurements of sea level, ocean winds, and waves that began with TOPEX/Poseidon. It took over as the reference mission on June 21, 2016, replacing Jason-2, and is fully operational with all redundant systems available.

Jason-2

Due to issues with the power supply on the Jason-2 spacecraft, the office of the French Space Operations Act at Centre National d'Études Spatiale (CNES; the French Space Agency), requested decommissioning of the Jason-2 satellite. On September 26, 2019, the decision to decommission Jason-2 was adopted by the four partner agencies for the mission: NASA,

[1] CFOSAT stands for Chinese–French Oceanography Satellite, which launched in October 2018.

[2] This line of missions includes TOPEX–Poseidon (1992–2006), Jason-1 (2001–2013), Jason-2 (2008–2019), and Jason-3 (launched in 2016). It will also include Sentinel-6A (planned for launch in late 2020) and Sentinel-6B (scheduled for 2025). Note that on January 28, 2020, the mission's partners announced that Sentinel-6A would officially be renamed Sentinel-6 Michael Freilich to honor Dr. Freilich's outstanding contributions to the mission and Earth science generally. To learn more, see "Symposium on Earth Science and Applications from Space with Special Guest Michael Freilich," in the March–April 2020 issue of *The Earth Observer* [**Volume 32**, **Issue 1**, pp. 4–18—*https://go.nasa.gov/2MZhBHI*]

CNES, the U.S. National Oceanic and Atmospheric Administration (NOAA), and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). Apart from occasional brief outages due to known issues with the spacecraft gyros, the availability and performance of all instrument data was excellent up to the planned passivation, which took place on October 10, 2019. Since July 2017, Jason-2 had occupied a long-repeat orbit (LRO) about 27 km (~17 mi) below Jason-3 It had been placed in that orbit to safeguard the orbit of Jason-3 and its successors while still providing maximum scientific and operational benefit. Prior to passivation, the LRO provided very dense ground-track spacing allowing Jason-2 to collect data more frequently, which has led to improved understanding of the marine gravity field.

Sentinel-3A and -3B

Sentinel-3A and -3B were launched in February 2016 and April 2018, respectively.[3] Similar to past missions in the reference orbit, a *tandem phase* between Sentinel-3A and -3B (both of which have high-inclination altimeters onboard) was performed until October 16, 2018, with a 30-second temporal separation between spacecraft. This allowed careful cross-calibration of the two satellites. Subsequently, Sentinel-3B was placed in a nominal orbit that is 140° out of phase[4] with Sentinel-3A, and both missions now provide sea-level measurements along high-inclination tracks as part of their routine operations. The overall quality of data from the Sentinel-3 constellation is excellent and they continue to meet all requirements.

Copernicus Sentinel-6/Jason Continuity of Service Mission and Beyond

Turning toward the future, the Copernicus Sentinel-6/Jason Continuity of Service (henceforth Sentinel-6) mission, the successor to Jason-3, is now in full development with the partner agencies, which include the European Space Agency (ESA), NASA, EUMETSAT, and NOAA, with CNES providing expert support in an advisory capacity. Operational continuity of Jason-3 is assured by the Sentinel-6 mission, consisting of two identical satellites, to be launched five years apart, that will occupy the reference orbit. The satellites will include radar capable of delivering high-resolution data along the ground track, a radiometer that has better long-term stability than the radiometers on previous Jason missions for global sea-level studies, and a higher-frequency channel to improve coastal altimetry data products.

[3] The Sentinel Missions are part of ESA's Copernicus Programme, which is part of the European Union's Earth Observation Program. They are detailed at *http://www.esa.int/Applications/Observing_the_Earth/Copernicus/Overview4*. Sentinel-3 and -6, are mentioned in that article.

[4] The Sentinel-3A and -3B satellites have the same period, altitude, and inclination, but when they cross the Equator they are separated by 140° of latitude.

There were presentations on several other new, upcoming and candidate missions in various stages of development, each with applications relevant to OST. These include (the):

- SARAL/AltiKa,[5] a high-inclination satellite K_a-band radar altimeter, in a drifting orbit since July 2016; it continues to perform nominally after six years in orbit.
- CFOSAT, a wind and wave scatterometer mission.
- Surface Water Ocean Topography (SWOT) mission, a joint mission by NASA and CNES, which is a high-resolution swath altimeter for the ocean, lakes, and rivers, planned for launch in 2021.
- Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL), which would carry a multi-frequency radar altimeter and microwave radiometer to measure and monitor sea-ice thickness and overlying snow depth.[6]

Each presentation included information on the mission's status and development plans. After discussing these missions and other issues concerning altimetry, the OSTST adopted the following two recommendations (among several other recommendations detailed in the full report):

- To minimize the likelihood of a gap in polar ocean and ice monitoring, the OSTST encourages agencies to strive to launch a high-resolution polar altimeter in the early 2020s (e.g., the proposed High Priority Candidate Mission, CRISTAL) and to maintain operation of CryoSat-2,[7] ICESat-2, and SARAL/AltiKa as long as possible.
- Although the OSTST recognizes the importance of the 5G spectrum for advances in telecommunications, using this spectral band has the potential to interfere with critical observations used by climate scientists, oceanographers, meteorologists, and operational users. In light of this, the OSTST recommends that governments and relevant agencies take steps to mitigate interference from 5G communications by regulation and enforcement as well as through improvements to future satellite designs.

[5] SARAL stands for Satellite with Argos (a French data-collection system) and AltiKa (itself a K_a-band altimeter). It is a cooperative altimetry mission between the Indian Space Research Organisation (ISRO) and CNES.

[6] CRISTAL is one of six high-priority candidate missions that are being studied to address European Union policy and gaps in Copernicus user needs, as well as to extend the current capabilities of the Copernicus space components.

[7] CryoSat-2 is an ESA environmental research satellite, launched in April 2010, which is collecting data on the polar ice caps and tracking changes in the thickness of the ice, with a resolution of ~1.3 cm (0.5 in).

Opening Plenary Session Highlights

Josh Willis [NASA/Jet Propulsion Laboratory (JPL)] began with welcoming remarks on behalf of all the project scientists, who (in addition to himself) include **Pascal Bonnefond** [CNES], **Eric Leuliette** [NOAA], **Remko Scharroo** [EUMETSAT], and **Craig Donlon** [ESA] who, unfortunately, was unable to attend the meeting in person this year.

Program managers presented the status of altimetry and oceanographic programs at their respective institutions including: **Nadya Vinogradova-Shiffer** [NASA], **Annick Sylvestre-Baron** [CNES], **François Parisot** [EUMETSAT], **Eric Leuliette** [NOAA], and **Pierre Féménias** [ESA].

In addition, **Benoit Meyssignac** [CNES] gave a presentation titled "How Accurate is Accurate Enough?" on the scientific and societal needs for additional improvements in the accuracy of sea level measurements. He demonstrated that further improvements in the accuracy of the sea-level record could help address scientific questions such as projections of future sea level, attribution of present-day rates of sea-level rise, and constraining Earth's energy imbalance.

Finally, **Patricia Ward** [Museum of Science and Industry, Chicago—*Director of Science Exhibitions*] gave a presentation titled "Engaging the Public in Addressing Climate Change," detailing numerous efforts on behalf of the Museum of Science and Industry to engage the public on the topic of climate change, focusing particularly on the "Extreme Ice Survey" Exhibit. Ward explained how the museum's exhibits were designed to inspire and empower visitors to explore a sustainable future for life on Earth.

Keynote and Splinter Session Highlights

The foci of the 16 splinter sessions (which include each of the topics grouped under Science Results in the list above) are listed in the Introduction. In addition, a special keynote science session was held after the plenary session. Space precludes describing all the sessions in detail, but complete coverage of the results can be found at the website mentioned in the Introduction. This report will focus on two of the splinter sessions that presented subjectively scientifically compelling results.

Science Keynotes

This special splinter session provided science presentations of general interest to the broad OST community.

Denis Volkov [NOAA's Atlantic Oceanographic and Meteorological Laboratory and University of Miami] gave a presentation on coastal sea-level signals associated with the Atlantic Meridional Overturning Circulation (AMOC), which is a feature of the general circulation of water in the Altantic Ocean that carries heat northward throughout both the Southern and Northern Altantic Oceans. The AMOC is thought to have a major impact on regional climate in Europe, Africa, and the Americas. **Figure 1** shows that dynamic sea-level changes in several key regions are strongly correlated with the strength of the AMOC. These results suggest that there is potential for multiyear predictability of these sea-level signals using current AMOC observations.

Satellite altimeter observations of ocean surface topography have always been challenging in the Polar Regions, where sea ice is present—sometimes

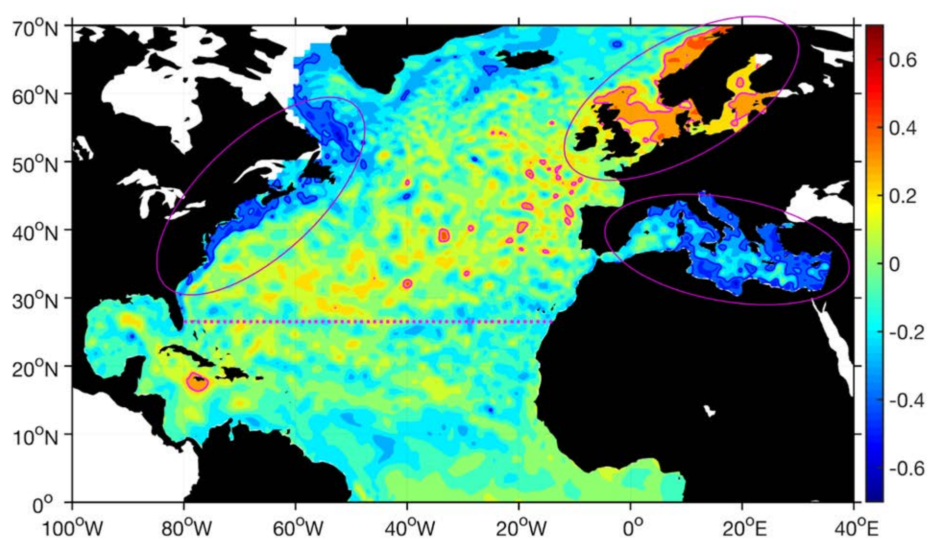

Figure 1. This map shows the correlation between the monthly AMOC strength and *dynamic sea level*—that is sea-level change related to changes in ocean currents or ocean dynamics. The three circled regions highlight locations where this dynamic sea-level change is either positively (red and yellow) or negatively (greens and blues) correlated with AMOC strength. **Image credit**: Denis Volkov

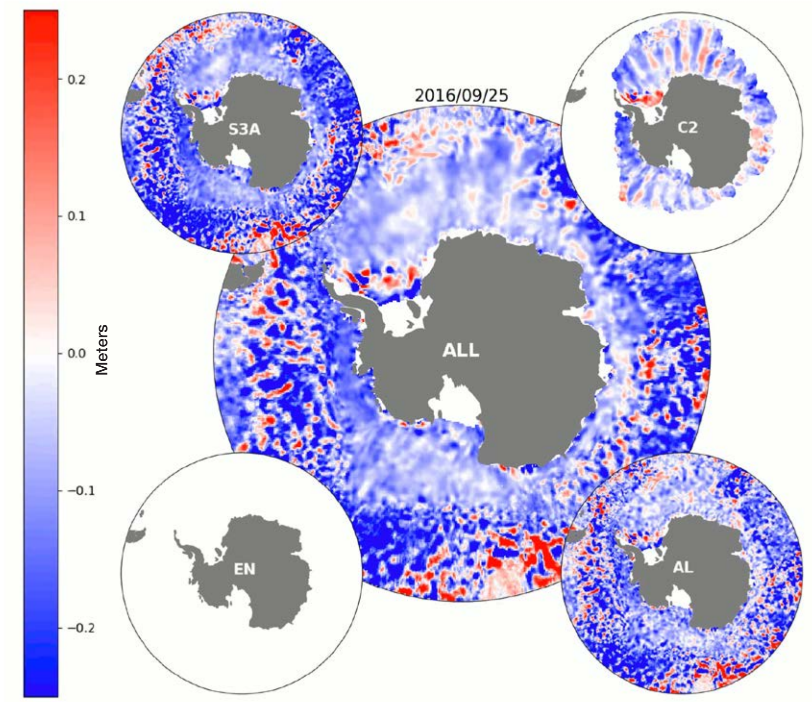

Figure 2. This map shows sea-level data in the Southern Ocean for late September 2016, when sea ice around Antarctica was near its maximum (the scale is in meters). Data from the Southern Ocean collected from three different satellites were used to generate the map in the center: Sentinel-3A (S3A), CryoSat-2 (C2), and SARAL/AltiKa (AL). Note that this image was taken from an animation that shows data from May 2011 to April 2018, which, in addition to the three satellites already named, also incorporates data from Envisat (EN) until it ceased operations in April 2012. This explains why one of the globes is blank. **Image credit**: Matthis Auger

year-round. **Matthis Auger** [Collecte Localisation Satellites (CLS), a CNES subsidiary] presented results from a new effort to merge data from the Jason missions, with data from Envisat,[8] CryoSat-2, and Sentinel-3, which have been specially processed to detect the ocean surface in cracks or leads in sea ice. **Figure 2** shows preliminary data from this effort for late September 2016, after the end of the Envisat mission, but when Sentinel-3A, SARAL/AltiKa, and CryoSat-2 provided data. Coverage is excellent, despite the fact that sea ice was near its maximum in the Southern Ocean on the date shown.

Application Development for Operations

Sea-level measurements from space have a wide variety of uses beyond the community of oceanographers and climate scientists that typically attend the OST STM. Many satellite altimeter products have been drafted into service to provide information from applications ranging from search and rescue efforts to environmental management. This splinter session was a forum to examine the development of and challenges associated with providing this kind of information to end users.

Ted Strub [Oregon State University] described a collaborative effort to create an ocean-forecasting system for use by Oregon fisherman. **Figure 3** on page 17 shows a snapshot from that the Northwest Association of Networked Ocean Observing Systems (NANOOS) Visualization System [NVS] Seacast (*http://nvs.nanoos.org/seacast*). It displays forecasts of ocean currents, temperatures and salinities based on a model designed by Alexander Kurapov [now at NOAA's National Ocean Service (NOS)] that assimilates along-track altimeter heights, satellite sea-surface temperature (SST), and coastal radar-derived surface currents. Strub described the challenge of making scientific data useful to end users. For example, fishermen need data available in near-real time to make decisions about their activities with the best information at hand. Kurapov noted that in order to provide useful information to these users, it is necessary for data providers to understand the decisions users have to make, as well as the uncertainty and tolerance for risk. Such efforts require close collaboration between scientists and users to be successful.

Closing Plenary Session Highlights

During the closing plenary session, spokespersons representing each splinter session provided responses to comments on key discussion items posed by the project scientists at the beginning of the meeting. **Shailen Desai** [NASA] gave an update on the status of the effort to retrack and reprocess data from the TOPEX/Poseidon mission. Several long-standing issues in the TOPEX/Poseidon data record are finally being addressed and corrected. The reprocessed TOPEX/Poseidon data likely will be finalized and publicly released within the next year.

Conclusion

During the closing session, the OSTST adopted the recommendations to prioritize polar ocean and ice monitoring through altimetry, and to take steps to mitigate interference from 5G communications with

[8] Envisat was a European Space Agency mission that launched in 2002 and lasted until 2012.

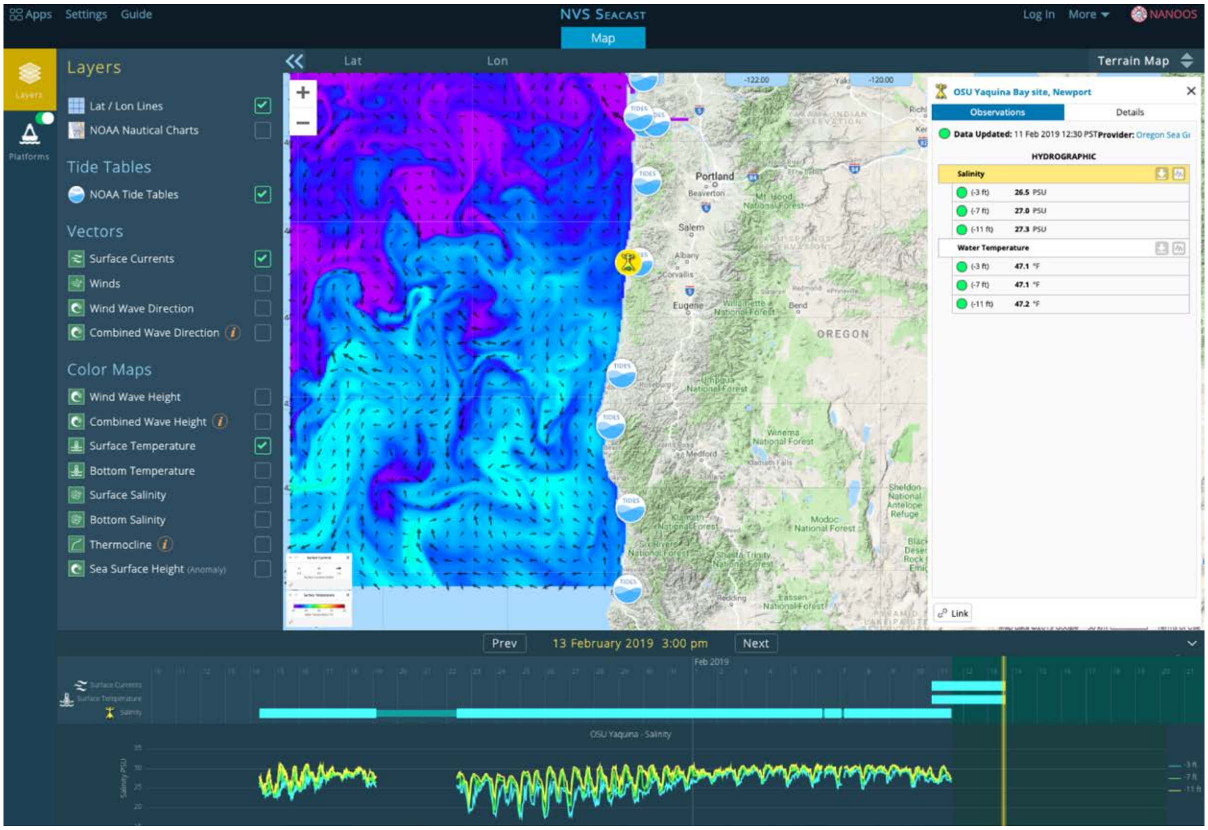

Figure 3. A screen shot from the NVS Seacast ocean forecasting system, showing a forecast of ocean currents and surface salinity. **Image credit:** Ted Strub

critical satellite observations, as well as to prioritize ongoing study and reprocessing of altimeter data from current and past missions. Other specific recommendations can be found in the complete OST STM report referenced in the Introduction.

As has become customary for such gatherings, this OST STM ended with a number of acknowledgements and kudos, several of which refer to recommendations made by the OSTST. The team acknowledged the various space agencies for maintaining the launch schedule of Sentinel-6 to overlap with Jason-3, and their ongoing support of data reprocessing efforts. Finally, on the eve of their retirement, the team extended a special appreciation to **Eric Lindstrom** [NASA Headquarters] who retired after 22 years as Program Scientist for Physical Oceanography, and **François Parisot** [EUMETSAT, *retired*] who has been responsible for managing the altimetry activities since 2003, and before worked for CNES and supported the launch of Jason-1 in 2001. The OSTST recognized both individuals for providing extraordinary leadership in satellite oceanography. Additional acknowledgements can be found in the full OST STM report link referenced in the Introduction.

The meeting fulfilled all of its objectives. It provided a forum for updates on the status of Jason-2 and Jason-3 and other relevant missions, programs, and detailed analyses of mission observations by the splinter groups. The team concluded that data from the Jason-2 and -3 altimeters continue to meet the accuracy and availability requirements of the science community.

The 2020 OST STM is scheduled for October 19-23, 2020, in Venice, Italy.[9]

Acknowledgment: This report is based on the official meeting report, which is referenced in the Introduction of this article, and which was prepared in cooperation with all of the OSTST chairs: **Josh Willis** [JPL] (author of this summary); **Pascal Bonnefond** [Observatoire de Paris, Laboratoire Systèmes de Référence Temps-Espace (SYRTE), CNES]; **Eric Leuliette** [NOAA]; **Remko Scharroo** [EUMETSAT]; and **Craig Donlon** [ESA]. ■

[9] **UPDATE**: In light of the ongoing COVID-19 pandemic, the “in-person” meeting has subsequently been cancelled. A virtual event is tentatively planned for the same dates.

Summary of the Joint Workshop on Emerging Technologies and Methods in Earth Observation for Operational Agricultural Monitoring

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Introduction

The Joint workshop on Emerging Technologies and Methods in Earth Observation for Operational Agriculture Monitoring took place February 25–27, 2020, at the National Agricultural Library in Beltsville, MD. NASA Harvest,[1] the U.S. Department of Agriculture (USDA), and Agriculture and Agri-Food Canada (AAFC) sponsored the meeting, which was held within the framework of the international Group of 20's (G20)[2] Group on Earth Observations Global Agricultural Monitoring Initiative (GEOGLAM).[3] The purpose of the workshop was to share recent results and advances from the research community relevant to operational agricultural monitoring using Earth-observation data and to identify gaps and challenges for the operational user community. Recognizing that significant advances in Earth-observing missions and data use are being made in the private sector, the workshop invited Harvest private-sector partners to share their recent developments. The presentations and discussions were aimed at:

- identifying priority areas for operational research and development (R&D) activities
- advancing the community's research activities;
- identifying applications that are approaching readiness levels suitable for transition to operational applications;
- identifying promising new satellite missions, technologies, data initiatives, and applications that would meet operational information needs; and
- discussing ideas for future national and international collaboration towards strengthening agricultural monitoring.

This article summarizes the workshop, which had 78 participants, including a number of international Harvest partners—see **Photo 1**. Sessions focused on:

- agency updates and priorities;
- improved methods for crop status and yield;
- fine-resolution Earth-observation data and methods;
- data fusion and applications;
- Earth-observing missions;
- high performance *cloud computing* (which allows remote processing of satellite data held in the cloud);

[1] For background on NASA Harvest and the NASA Harvest Consortium, see "Summary of the First NASA Harvest Conference" in the September–October 2019 issue of *The Earth Observer* [**Volume 31**, **Issue 5**, pp. 38–43—*https://go.nasa.gov/3dCXGtk*].
[2] The G20 is an international forum comprised of governments and central bank governors from 19 countries and the European Union.
[3] GEOGLAM helps to coordinate satellite monitoring observation systems in different regions of the world in order to enhance crop production projections and weather forecasting data. Learn more at *http://earthobservations.org/geoglam.php*.

Photo 1. Participants at the Joint Workshop on Emerging Technologies and Methods in Earth Observation for Operational Agricultural Monitoring in Beltsville, MD. **Photo credit:** Mary Miktish

- recent developments in soil-moisture monitoring;
- private-sector technical innovations; and
- new contexts for agricultural monitoring.

Breakout discussion groups focused on Cloud Computing, Public–Private Partnerships, Soil Moisture and Evapotranspiration, and Crop Type and Yield Estimation. Recommendations to the larger communities that arose from session discussions are presented at the end of each session summary. The agenda and the presentations of the meeting are available at *https://go.nasa.gov/3cBNqjZ*. There is a tab to click on to view each day's presentations.

Operational Earth Observation Monitoring Systems

This session consisted of keynote presentations and updates on new developments and needs in Earth observation-based agriculture monitoring by representatives of NASA Harvest, GEOGLAM, AAFC, and USDA's Foreign Agricultural Service (FAS) and National Agricultural Statistics Service (NASS).

Mark Brusberg [USDA, Office of the Chief Economist—*Chief Meteorologist*] gave the opening presentation emphasizing the importance of EO and other data for objectivity in their data analysis, with the challenge that information used to inform their World Agricultural Supply and Demand Estimates (WASDE) report needs to be reliable, timely, and consistent. (The WASDE report is a major economic report produced monthly to show farmers, policymakers, and traders what's going on in the world of farm commodity forecasts.)

Brad Doorn [NASA Headquarters, Applied Sciences Program—*Program Manager for Water Resources and Agriculture Research*] focused on the role of Harvest in identifying how NASA can contribute to agricultural monitoring more effectively—e.g., NASA is working with USDA and the private sector to gain a better understanding of how to improve the quality of NASA products and tools, which will enable better decision making for the end user.

Chris Justice [University of Maryland, College Park—*Chief Scientist for NASA Harvest*] gave a presentation on the status of the NASA Harvest program and the current foci of GEOGLAM. He highlighted a number recent trends in the field, including the growth in the use of data from the several of the European Copernicus Sentinel missions,[4] the increased use of machine learning and artificial intelligence, the availability of fine-resolution data (for example, from Planet),[5] and increasing private-sector involvement in agricultural information technology.

A panel of agricultural agency representatives, including **Rick Mueller** [USDA NASS], **Bob Tetrault** [USDA FAS], and **Catherine Champagne** [AAFC], highlighted the overlapping priorities of their respective agencies. These priorities include development of innovative approaches to determine soil moisture and evapotranspiration; active engagement of researchers in data integration and modeling; development of reliable and affordable cloud-computing services; creation of consistent long-term, Earth-observation data products; offering domestic and international partners training in field data-collection methods and tutorials on the use of Earth-observation data for agricultural monitoring (e.g., identifying crop type and status and assessing vulnerability to adverse weather); and providing feedback to the space agencies and data providers on needed products and services.

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[4] The Sentinels are described at *http://www.esa.int/Applications/Observing_the_Earth/Copernicus/Overview4*.

[5] *Planet* was one of several private companies with representatives at this workshop. Planet operates more than 150 satellites that together provide a high-resolution dataset of Earth observation imagery, with a combination of coverage, frequency, and 3–5 m (10–16 ft) resolution. For more information see *https://www.planet.com/products/planet-imagery*.

Photo 2: [*Counterclockwise from left*] **Michael Humber** [NASA Harvest], **Benjamin Koetz** [ESA], and **Christina Lee** [NASA/Jet Propulsion Laboratory] each gave presentations on emerging technologies in the agriculture sector. **Photo credit**: Mary Mitkish and Meghavi Prashnani

Using Earth-Observation Data and Information Systems for Agricultural Monitoring

Workshop participants learned about recent research and advances in crop-type mapping, crop-area estimation, crop emergence, tillage and tillage intensity, automatic field delineation, within-season crop monitoring, fallow-area mapping, and crop-mask development—see **Photo 2**. Continental-scale, multiyear analysis of crop area over North and South America at moderate resolution [~30 m (98 ft)]), supported by probability-based field data collection and high-performance computing, is providing good results. Data from the European Copernicus Sentinel missions are now being used extensively at the regional scale and methods are starting to be tested on multiyear datasets. For example, the increased frequency of acquiring visible, near-infrared, and shortwave infrared (SWIR), moderate-resolution data from Sentinel-2 at critical times during the growing season is improving crop-monitoring results overall (e.g., crop-acreage estimation, yield estimation, drought, and damage). The long-term continuity of Sentinel data provides a strong case for investing in developing operational methods. The mandated use of Earth observation data in the European Common Agricultural Policy (CAP) is also increasing the uptake of such data at the national level for operational agricultural monitoring in Europe.

The expansion of Harmonized Landsat and Sentinel (HLS) data to global coverage will increase the use of merged time-series data. However, the lack of robust cloud detection in Sentinel-2 data remains an issue. Moderate-resolution C-Band synthetic aperture radar (SAR) data from Sentinel-1(with 12-day coverage) are being tested for different cropping systems to overcome problems of persistent cloud cover. The transition from using Moderate Resolution Imaging Spectroradiometer (MODIS) to Visible Infrared Imaging Radiometer Suite (VIIRS)[6] data is underway for monitoring global/regional crop conditions. Continuity products from MODIS to VIIRS are needed to form a consistent long-term, multiyear time-series. Initial analysis of multipolarization, multifrequency RADARSAT[7] data collected for Canada is producing good results—although the data policy is complex and will likely be an obstacle for broader data uptake by the research community. Airborne SAR data are being used to simulate analysis for the multifrequency SAR data that are expected from the NASA–Indian Space Research Organisation (ISRO) SAR [NISAR] mission, due for launch in 2022. Analysis of thermal data from the experimental ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) sensor on the International Space Station is providing early results on monitoring crop stress. Hyperspectral data from the experimental Vegetation and Environment monitoring on a New Micro Satellite (VENµS) microsatellite mission[8] are also being investigated for agricultural applications.

The increasing coverage of commercial fine-resolution satellite data [<5 m (<16 ft)] and recent efforts for the research community to access and evaluate the data are leading to its increased visibility and use. While the cost and licensing of fine-resolution data are obstacles for broad usage of the data, these data are presenting new opportunities for researchers working on smallholder farming systems with small fields and diverse crops. Fine-resolution data are also being tested as input to precision farming activities, e.g., showing within-field yield variability. Worldview-2[9] data—with its SWIR coverage—are proving to be useful at the subfield scales. Planet is bringing large parts of Earth under near-daily observation at fine resolution, with a constellation of small satellites. The data volume being collected is vast and outpaces the ability to fully utilize the data. To more effectively harness the flood of information from these constellations will require simplified and streamlined data access (e.g., via easy download of data or cloud storage), intercalibration of data from the large number of sensors, and easy tools for data preprocessing and analysis.

Next came presentations from **Jeff Masek** [NASA's Goddard Space Flight Center] and **Benjamin Koetz** [European Space Agency (ESA)] that provided insight into the sensors that will provide long-term data continuity around which operational systems can be developed. Masek discussed plans for Landsat and MODIS/VIIRS data continuity in the U.S., and Koetz discussed future plans for ESA's Sentinels. These U.S. and European missions provide a strong basis for Earth observation-based operational agricultural monitoring. Similarly, planning for continued private-sector missions will provide dynamic data continuity at fine resolution as commercial data and product characteristics continue to improve.

Recommendations Related to Using Earth-Observation Data in Agricultural Monitoring

- Prioritize global production of Harmonized Landsat-Sentinel (HLS) data and their continuation with future Landsat and Sentinel instruments—including version reprocessing.

Recommendations continue on next page.

[6] MODIS flies on NASA's Terra and Aqua platforms. VIIRS flies on the Suomi National Polar-orbiting Partnership (NPP) and National Oceanic and Atmospheric Administration-20 (NOAA-20) satellites.

[7] RADARSAT is a Canadian Earth observing satellite program overseen by the Canadian Space Agency. The program has included RADARSAT-1 (1995–2013), RADARSAT-2 (2007–Present), and the RADARSAT Constellation (first launch of three in 2019).

[8] VENµS is a cooperative effort between government agencies and private sector entities in France and Israel.

[9] Worldview-2 is a commercial satellite operated by DigitalGlobe.

- Provide support for MODIS-VIIRS intercalibration, with a focus on providing consistent vegetation indices (e.g., Normalized Difference Vegetation Index) on actionable time scales rather than those optimized based on orbital characteristics or radiometry (seven days is ideal for reporting).

- Encourage NASA and ESA coordination on missions to enable data product synergy between NISAR and Radar Observing System for Europe L (ROSE-L)[10] data.

Using Earth Observation for Soil Moisture and Evapotranspiration

Soil moisture (SM) and evapotranspiration (ET) are important variables related to crop condition and growth. There are many techniques available to collect SM and ET data using ground-based instrumentation at the plot scale, but these are difficult to implement and scale up to cover larger areas. Recent Earth observing technology [e.g., NASA's Soil Moisture Active Passive (SMAP), ESA's Soil Moisture Ocean Salinity (SMOS), and the National Oceanic and Atmospheric Administration's (NOAA) Geostationary Operational Environmental Satellite–Series R (GOES-R) missions] has provided the means to derive temporally consistent coverage of SM and ET. In general, these products have been at coarse resolution, but various downscaling methods, including the use of moderate-resolution data, are providing products at a range of spatial scales. The short history of these data products does not provide the longer-term record needed to place current conditions in a historical context, and there is a need generally for long-term data continuity. A number of satellite-based SM and ET products do exist, but to date there have been few intercomparison studies, meaning that users are unsure of which products work well under different circumstances. The participants discussed challenges and caveats associated with the derivation of accurate estimates of ET and SM using satellite data. The OpenET Project (*https://etdata.org*), which is aimed at bringing together different open-source methods for satellite-based ET on a common platform, will help address some of these issues.

[10] ROSE-L is one of six high-priority candidate missions that are being studied to address European Union policy and gaps in Copernicus user needs. Learn more at *https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Copernicus_High_Priority_Candidates*.

Michael Cosh [USDA's Agricultural Research Service] stressed the importance of soil moisture in monitoring drought. He presented updates on recent developments from the U.S. National Soil Moisture Network (*http://nationalsoilmoisture.com*)—see **Figure**. The mandating of the use of both satellite and *in situ* measurements in national drought assessments is driving the advances and expanded use of these technologies.

Farmers have limited experience interpreting information on soil moisture and need to have hydrological information translated into actionable information (e.g., thresholds for soil trafficability, drought, and irrigation decision points). Such application-ready information products at the field scale could help decision making. Data from planned SAR missions [i.e., NISAR and the ESA ROSE-L (L-Band SAR)] could provide such products. Coordination between these two missions is recommended, so that data can be used synergistically.

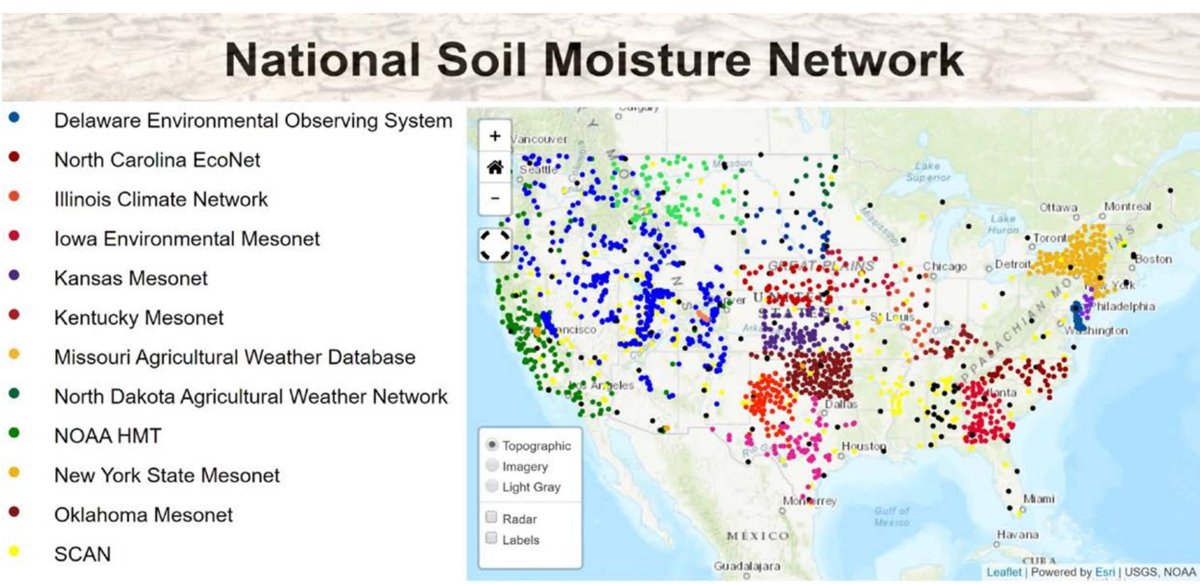

Figure. The U.S. National Soil Moisture Network brings together multiple soil-moisture data sources across federal and state *in situ* monitoring networks, Earth-observation data, and modeling capabilities, and provides a forum for product intercomparison. **Image credit:** National Soil Moisture Network

Recommendation Related to Earth Observations for Soil Moisture and Evapotranspiration

- Expand intercomparison and validation efforts for Earth observation-based soil moisture and evapotranspiration products and model outputs, which would lead to guidance on which products work best where, under different conditions, and in different stages of the growing season.

In situ Data for Earth Observation-Based Agriculture Monitoring

Several studies have compared the application of different machine-learning methods to agricultural monitoring using Earth observation data. The need for accurate and reliable results over large areas has put a greater emphasis on requirements for appropriate amounts of high-quality data to train and validate models. There was a consensus from the workshop participants that insufficient field data for training and validation severely limits the utility of automated results. Sharing field data and analysis tools, as well as the output products from the crop type and yield mapping exercises, would help advance the discipline. ESA's Sentinel-2 for Agriculture (Sen2Agri) system (*http://www.esa-sen2agri.org*) provides an example of an open-access analysis tool that can be adapted for local use. Some studies make use of fine-resolution satellite data as surrogates for ground-truth information. However, the limitations of the fine-resolution interpretation need to be evaluated and included in analyses and reporting.

Satellite-based yield estimation is particularly limited by the availability of field data. Collection of yield data in the field is time consuming and field surveys using different methods lead to inconsistent results. Two reasons for these inconsistencies are that field data are often inadequate representations of large areas and that data collection standards are lacking. For example, while data collected from combine harvesters provide a source of large amounts of subfield data, considerable effort is required to calibrate the data before they can be used. Similarly, data are collected by advanced farming systems on planting and midseason applications. The availability, access, and robustness of these data need to be better understood, and privacy concerns must be addressed.

The participants recognized the need for a common platform for *in situ* data sharing, wherein ground data can be shared in a standardized format that can be easily viewed and overlaid with other datasets. There was a general agreement on the need for increased availability of *in situ* data as well as sharing of code, validation data, and derived products (e.g., crop-type masks). Participants also suggested that the journals and funding agencies could help effect this change.

Recommendations Related to Using In Situ *Earth-Observation Data for Agricultural Monitoring*

- Standardization of a minimum set of field data to be collected for crop type mapping and yield modeling as well as sharing through a common platform—including leveraging the existing efforts under GEOGLAM's R&D network and the Joint Experiment for Crop Assessment and Monitoring (JECAM).
- Identify priority regions/countries for *in situ* data collection.
- Establish funding support for long term *in situ* data collection and incentives and business models for data sharing.

Cloud Computing Technology for Earth Observation-Based Agriculture Monitoring

The exponential increase in the volume of satellite data presents a challenge for most end users. The traditional approach of downloading and processing data on local machines is being replaced by cloud computing, leading to a paradigm shift in data processing with considerable potential in terms of scalability, speed, and infrastructure. In the cloud environment, data storage is inexpensive and computing costs are generally affordable. However, egress costs for transferring data from the cloud storage to another location (e.g., a different cloud region or an on-premises cluster) are currently high. If all users are in the same cloud environment, egress costs could be reduced. Regional-to-global-scale analysis is now accessible to a larger number of users through cloud computing via platforms such as Google Earth Engine. It should be noted that the more the Earth-observation community uses the cloud, the more the community benefits and costs are reduced. In this way, cross-community coordination and collective lesson sharing is warranted to ensure that cloud solutions meet shared needs. Coordination among agencies serving data through public cloud servers would also greatly benefit the community and could potentially be coordinated through the Committee on Earth Observing Satellites (CEOS)[11] to make these systems interoperable.

Current cloud computing services have several limitations, including an unfamiliar analysis approach for many, slow processing and access speeds (especially for

[11] CEOS is a consortium of 62 agencies operating 170 satellites worldwide that work together to ensure international coordination of civil, spacebased, Earth-observation programs for the benefit of all.

free versions), safety and privacy of internal data, shifting and opaque cost structures, and unavailability of some required datasets via the cloud. For example, for USDA and AAFC, the current cloud-based services are not set up for uploading confidential datasets, which are integral to their analyses. As a result, these organizations thus far have made limited use of the cloud. Different regional locations of Earth-observation data in cloud storage also create barriers to cloud usage: e.g., Landsat data are held in a U.S. region while Sentinel data are held in a European region, resulting in higher egress costs for users who wish to use these datasets concurrently. Hosting datasets that will be used together in the same location would help users avoid transfer costs.

Currently, the choice to use a local server infrastructure or use cloud computing depends on the use case and there is a tradeoff between speed, storage, and cost. Cost is involved at all stages: storage, procurement, migration within the cloud, and migration between a local server and the cloud (i.e., downloading and uploading).

In Europe, there are a number of efforts to provide cloud-based processing capabilities—for example, through the Copernicus Data and Information Access Services (DIAS) platforms and the European High Performance Computing (EuroHPC).[12] A number of international groups use Google Earth Engine, which allows data and code sharing and has user groups for exchanging information. To ensure reproducibility of analyses and products created using Google Earth Engine, developers should provide the Google Earth Engine version in addition to the code and the data, since functionality may change across versions.

A current challenge with implementing cloud computing is that traditional analysts are not familiar with the cloud-based services, and the technological barrier to entry is high. This calls for well-structured training packages or online tutorials focused on applying cloud computing to different aspects of agricultural monitoring. There is a need for certification programs or online courses focused on agricultural monitoring using cloud computing. The agricultural monitoring community could also build data and analysis platforms around more-efficient cloud architectures.

Cloud services are evolving and users are currently evaluating the pros and cons of cloud versus local network server infrastructure, as well as hybrid approaches that split processes between local and cloud-based processing and storage systems, but there is currently no consensus on the best approach for analysis. The GEOGLAM program has recently launched a coordination initiative to document cloud-computing lessons learned in order to help accelerate the adoption of best-fit, cloud-based solutions.

Recommendations Related to Cloud Computing for Earth Observation-Based Agriculture Monitoring

- Colocate Landsat, Sentinel, and combined HLS datasets in cloud environments accessible to users with little if any egress charges.
- Increase emphasis on training in the use of cloud computing for agricultural monitoring.
- Reduce the redundancy of common data processing to reduce cost of cloud computing, e.g., by providing preprocessed data.
- Secure, user-friendly, and affordable cloud computing services—including transparent and "locked-in" pricing possibilities.

Fostering Private–Public Partnerships (PPP) in Agricultural Monitoring

This session consisted of presentations from prominent private sector companies working on Earth observation-based agriculture monitoring, namely Indigo Ag, The Climate Corporation, Corteva, AgriScience, Dev Seed, and One-Soil. They presented innovations in crop growth and crop-health monitoring as well as on the use of drones and Internet of Things (IOT)[13] technologies for monitoring crop/soil health and for increasing productivity. Such private companies are skilled in using artificial intelligence and machine-learning techniques in precision agriculture and have innovative ideas for improving agricultural monitoring at the farm scale. They are taking advantage of the increase in satellite data availability, crowd-sourced data, low-cost ground sensors, and the emerging area of precision farming. Related developments are also happening through public-supported research, aimed at increasing the uptake of new technologies.

The private sector usually has strong connections to the end users of the information and a good idea of what information is needed (e.g., scale, timing, and latency) and how it fits into farm or corporate decision making. Meanwhile, government-supported researchers typically have technical expertise (e.g., in Earth-observation data analysis, data science, and modeling). Collaboration between the private and public sectors

[12] EuroHPC is a joint undertaking between the EU and European countries to develop a world-class supercomputing ecosystem in Europe.

[13] IOT is a system of interrelated computing devices and mechanical and digital machines, each provided with a unique identifier and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.

in this area would therefore be mutually beneficial and there is a need to improve communication between the communities. Codevelopment and cofunding are more likely to result in successful collaboration. Commercial interests can be addressed, e.g., by sharing data with reduced precision or at a coarser scale than the commercial product.

During the meeting, the participants proposed creating a "clearinghouse" for parties interested in partnership that would match research and applications in order to facilitate sharing of experience, data, models, and product validation approaches, while also identifying and documenting what works and what does not. Harvest has a PPP focus area, and has previously proposed a similar facilitation mechanism, with the support of The Climate Corporation, Corteva AgriScience, and Planet.

Recommendations for Fostering Public–Private Partnerships in Agricultural Monitoring

- Advance the public–private partnerships associated with use of Earth observations for providing actionable farm-level information.
- Develop a facilitation mechanism and community forum to link the private sector and the research communities around Earth observations.

Emerging Areas in Earth Observation-Based Agriculture Monitoring

The meeting participants also discussed a number of Earth observation agricultural application areas that warrant increased development, including environmental impacts of agriculture (e.g., soil health, water and air quality, and biodiversity); adaptation to climate change; greenhouse-gas monitoring; sustainability of food productions on large-scale sustainable farming practices (e.g., crop rotation, no-till techniques, and irrigation mapping and management); and crop pest and disease identification.

Agriculture is an important land use, tied closely to human livelihood, and is integral to the sustainability agenda and the UN Sustainable Development Goals.[14] Satellite-based metrics can be used to monitor progress towards meeting the goals associated with food security. GEOGLAM (in an effort co-led by Harvest) is defining these Earth observation-based metrics, known as "Essential Agricultural Variables for GEOGLAM." Agriculture also has an important aspect in building resilience to climate change, a contribution that is being implemented through Climate Smart Agriculture initiatives,[15] such as integrated farming practices, soil carbon management, soil health improvement, proactive drought management, and efficient irrigation. Monitoring agricultural land use and forecasting production are important aspects of managing our agricultural resources. Fine-resolution Earth-observation data can be used to track changing land-use practices and evaluate the effectiveness of development, policy, or farming practice interventions (e.g., farmer subsidies, drought-resistant varieties, improved irrigation, or nutrient and pest management).

The changing climate is characterized by an increasing frequency of extreme weather events (e.g., drought, flooding, winter kill, and tornadoes). Monitoring these weather-related agricultural disasters requires a rapid response to quantify the extent and impacts of such events. There is also a need to take the initiative in cases of potential shortfalls in production. In this context improved numerical weather forecasting is needed, i.e., beyond current forecasting capabilities (10 days) to cover an entire growing season—and with sufficient accuracy to inform decision making.

Conclusion

This workshop provided a forum to share information on new developments in agricultural monitoring among operational agencies, researchers, and the private sector. It also presented an opportunity for attendees to converge on a number of components of a research agenda geared toward developing improved operational capabilities for Earth observations, as well as developing new contacts and collaborations

In addition to the recommendations that have already been listed under individual session summaries, there were a couple more identified as "Community Best Practices" that emerged from this workshop. These included placing increased emphasis on having principal investigators share data about their projects/missions (which they acknowledged will be driven to some degree by the funding agencies), including details on "best practices"—e.g., methods, code, validation

[14] In 2015 the UN adopted the 2030 Agenda for Sustainable Development, which provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At the core of this agenda are 17 Sustainable Development Goals (SDGs). To learn more, visit *https://sustainabledevelopment.un.org/?menu=1300*.

[15] Climate Smart Agriculture refers to an integrated approach the landscape management—i.e., cropland, livestock, forests, and fisheries—that address the interlinked challenges of food security and climate change. To learn more, see *https://www.worldbank.org/en/topic/climate-smart-agriculture*.

datasets, and output maps. The participants agreed that there was a need to share methods, codes, map products, and validation data associated with peer-reviewed articles and to establish a community initiative to generate a compilation product of global crop type mapping at moderate or fine resolution. They also agreed to develop intercomparison studies to identify the most-appropriate, satellite-based yield models and to include uncertainty measures with yield forecasts, with increased focus on anomalous seasons and the frequency and timeliness of model outputs.

This workshop was a grand success in bringing together ideas from different public and private organizations working on Earth observation-based agriculture monitoring. This workshop series on emerging Earth-observation technologies is proving to be a useful way to showcase research that is focused on operational application to agriculture monitoring and to solicit feedback from operational agencies that use Earth-observation data. NASA Harvest plans to convene another meeting in this series in 2022. ■

Tutorial Video: Getting Started with NASA Worldview

A step-by-step tutorial video that shows how to use NASA Worldview is now available on YouTube at *https://youtu.be/nW8JZJ-5g_0*.

This demonstration introduces users to the NASA Earth Observing System Data and Information System (EOSDIS) Worldview imagery mapping and visualization application. This tool provides the capability to interactively browse over 900 global, full-resolution, satellite-imagery layers. Many of these layers are updated daily and are available within three hours of observation. Also available are geostationary imagery layers which are provided in ten-minute increments for the last 30 days. These full-disk hemispheric views allow for almost real-time viewing of changes occurring around most of the world—essentially showing the entire Earth as it looks "right now." Worldview's easy-to-use map interface lets you interactively explore NASA Earth-science imagery to see hurricanes forming, wildfires spreading, icebergs drifting, and city lights illuminating.

Explore NASA Earth science data imagery using NASA Worldview: *https://worldview.earthdata.nasa.gov*.

NASA's ICESat-2 Measures Arctic Ocean's Sea Ice Thickness, Snow Cover

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

Arctic sea ice helps keep Earth cool, as its bright surface reflects the Sun's energy back into space. Each year scientists use multiple satellites and datasets to track how much of the Arctic Ocean is covered in sea ice, but its thickness is harder to gauge. Initial results from NASA's new Ice Cloud and land Elevation Satellite-2 (ICESat-2) suggest that the sea ice has thinned by as much as 20% since the end of the first ICESat mission (2003–2009)—contrary to existing studies that find sea-ice thickness has remained relatively constant in the last decade.

ICESat-2 carries a laser altimeter, which uses pulses of light to precisely measure height down to about an inch. Each second, the instrument sends out 10,000 pulses of light that bounce off the surface of Earth and return to the satellite and records the length of time it takes to make that round trip. The light reflects off the first substance it hits, whether that's open water, bare sea ice, or snow that has accumulated on top of the ice, so scientists use a combination of ICESat-2 measurements and other data to calculate sea ice thickness.

By comparing ICESat-2 data with measurements from the European Space Agency's CryoSat-2 mission, which launched in 2010, researchers have also created the first satellite-based maps of the amount of snow that has accumulated on top of Arctic sea ice, tracking this insulating material.

"The Arctic sea ice pack has changed dramatically since monitoring from satellites began more than four decades ago," said **Nathan Kurtz** [NASA's Goddard Space Flight Center (GSFC)—*ICESat-2 Deputy Project Scientist*]. "The extraordinary accuracy and year-round measurement capability of ICESat-2 provides an exciting new tool to allow us to better understand the mechanisms leading to these changes, and what this means for the future."

Arctic sea ice thickness dropped drastically in the first decade of the twenty-first century, as measured by the first ICESat mission from 2003 to 2009 and other methods. CryoSat-2 has measured a relatively consistent thickness in Arctic sea ice since then. With the launch of ICESat-2 in 2018, researchers looked to this new way of measuring sea-ice thickness to advance the study of this data record.

"We can't get thickness just from ICESat-2 itself, but we can use other data to derive the measurement," said lead author **Alek Petty** [GSFC]. For example, the researchers subtract out the height of snow on top of the sea ice by using computer models that estimate snowfall. "The first results were very encouraging."

In their study, published recently in the *Journal of Geophysical Research: Oceans (JGR Oceans)*, Petty and his colleagues generated maps of Arctic sea-ice thickness from October 2018 to April 2019 and saw the ice thickening through the winter as expected.

Overall, however, calculations using ICESat-2 found that the ice was thinner during that time period than what researchers have found using CryoSat-2 data. Petty's group also found that small but significant 20% decline in sea ice thickness by comparing February/March 2019 ICESat-2 measurements with those calculated using ICESat in February/March 2008—a decline that the CryoSat-2 researchers do not see in their data.

These are two very different approaches to measuring sea ice, Petty said, each with its own limitations and benefits. Whereas ICESat-2 uses a lidar to measure height, CryoSat-2 uses a radar, which mostly passes through snow to measure the top of the ice. Radar measurements like the ones made by CryoSat-2 could be thrown off by seawater flooding the ice, he noted. In addition, ICESat-2 is still a young mission and the computer algorithms are still being refined, he said, which could ultimately change the thickness findings.

"I think we're going to learn a lot from having these two approaches to measuring ice thickness. They might be giving us an upper and lower bound on the sea ice thickness, and the right answer is probably somewhere in between," Petty said. "There are reasons why

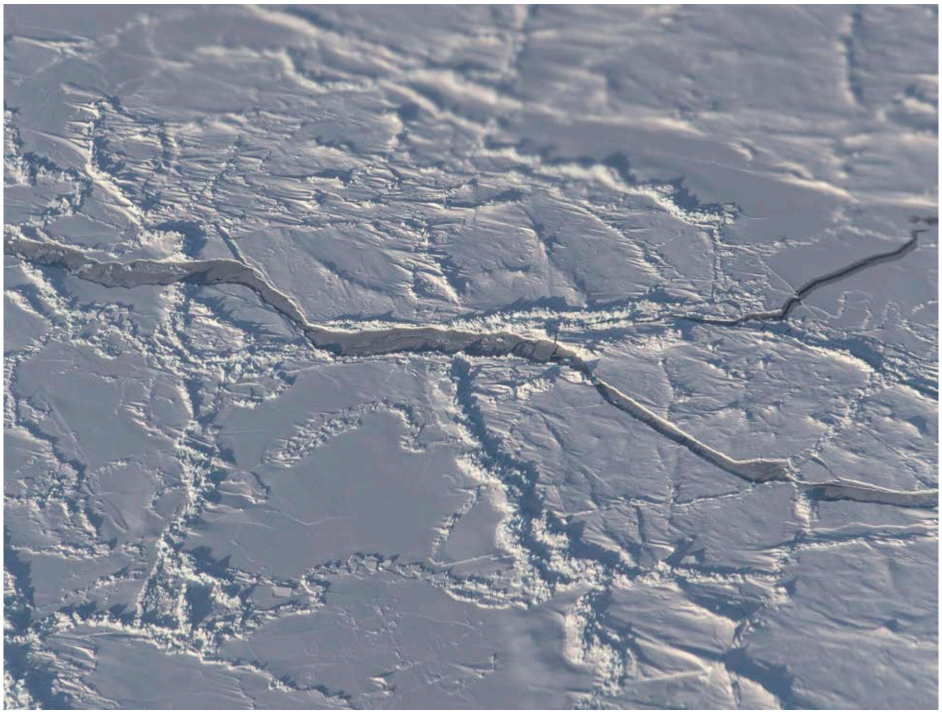

Photo. Scientists have used NASA's ICESat-2 satellite to measure the thickness of Arctic sea ice, as well as the depth of snow on the ice. Here, ridges and cracks have formed in sea ice in the Arctic Ocean. **Credit:** NASA/Jeremy Harbeck

ICESat-2 estimates could be low, and reasons why CryoSat-2 could be high, and we need to do more work to understand and bring these measurements in line with each other."

With ICESat-2 and CryoSat-2 using two different methods to measure ice thickness—one measuring the top of the snow, the other the boundary between the bottom of the snow layer and the top of the ice layer—researchers realized they could combine the two to calculate the snow depth.

"This is the first time ever that we can get snow depth across the entire Arctic Ocean's sea ice cover," said sea ice scientist **Ron Kwok** [NASA/Jet Propulsion Laboratory] and author of another study in JGR Oceans. "The Arctic region is a desert—but what snow we do get is very important in terms of the climate and insulating sea ice."

The study found that snow starts building up slowly in October, when newly formed ice has an average of about 2 in (5 cm) of snow on it and multiyear ice has an average of 5.5 in (14 cm) of snow. Snowfall picks up later in the winter in December and January and reaches its maximum depth in April, when the relatively new ice has an average of 6.7 in (17 cm) and the older ice has an average of 10.6 in (27 cm) of snow.

When the snow melts in the spring, it can pool up on the sea ice—those melt ponds absorb heat from the Sun and can warm up the ice faster, just one of the impacts of snow on ice. ■

NASA Space Laser Missions Map 16 Years of Ice Sheet Loss

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

Using the most advanced Earth-observing laser instrument NASA has ever flown in space, scientists have made precise, detailed measurements of how the elevations of the Greenland and Antarctic ice sheets have changed over 16 years.

The results provide insights into how the polar ice sheets are changing, demonstrating definitively that small gains of ice in East Antarctica are dwarfed by massive losses in West Antarctica. The scientists found the net loss of ice from Antarctica, along with Greenland's shrinking ice sheet, has been responsible for 0.55 in (14 mm) of sea level rise between 2003 and 2019—slightly less than a third of the total amount of sea level rise observed in the world's oceans—see **Figure**.

The findings come from NASA's Ice, Cloud and land Elevation Satellite-2 (ICESat-2), which launched in 2018 to make detailed global elevation measurements, including over Earth's frozen regions.[1] By comparing the recent data with measurements taken by the original ICESat from 2003 to 2009, researchers have generated a comprehensive portrait of the complexities of ice-sheet change and insights about the future of Greenland and Antarctica.

The study found that Greenland's ice sheet lost an average of 200 gigatons of ice per year, and Antarctica's ice sheet lost an average of 118 gigatons of ice per year. One gigaton of ice is enough to fill 400,000 Olympic-sized swimming pools or cover New York's Central Park in ice more than 1000 ft (300 m) thick—reaching higher than the Chrysler Building.

"If you watch a glacier or ice sheet for a month, or a year, you're not going to learn much about what the climate is doing to it," said **Ben Smith** [University of Washington], the lead author of the new paper, published online in *Science* April 30, 2020.[2] However, "We now have a 16-year span between ICESat and ICESat-2 and can be much more confident that the

[1] To learn more about ICESat-2, see the News story on page 26 of this issue.

[2] To read the study, visit *https://science.sciencemag.org/content/early/2020/04/29/science.aaz5845*.

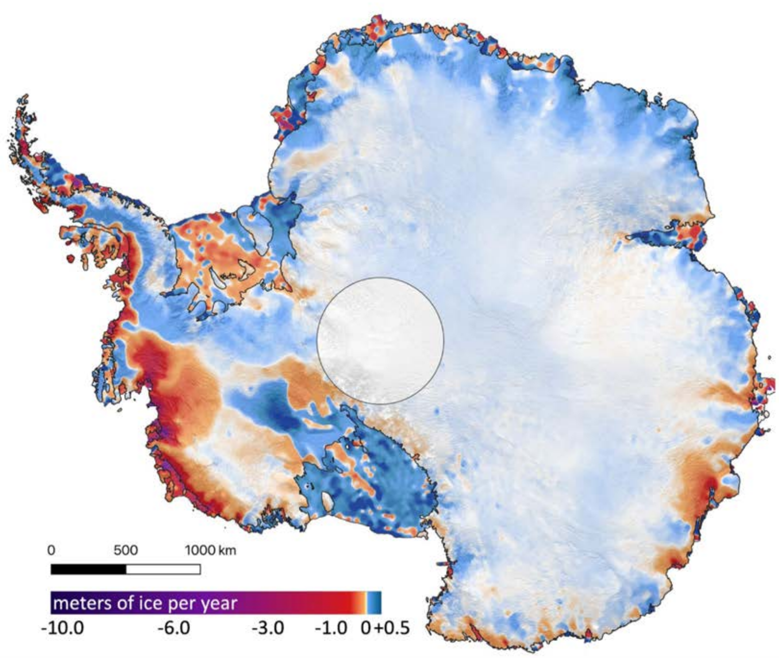

Figure. This map shows the amount of ice gained or lost by Antarctica between 2003 and 2019. Purple and red areas show large average rates of ice loss near the coasts, while blue areas show smaller rates of ice gain in the interior. The ice lost near the coasts, especially for West Antarctica and the Antarctic Peninsula, vastly outweighs gains in the interior. The Thwaites and Crosson ice shelves (seen just below the peninsula) have thinned the most. The two ice shelves have lost 16 ft (5 m) and 10 ft (3 m) of ice per year, respectively, between 2003 and 2019. The circle in the middle is over the South Pole where the instrument does not collect data. **Credit:** Smith *et al.*/Science changes we're seeing in the ice have to do with the long-term changes in the climate."

ICESat-2's instrument is a laser altimeter, which sends 10,000 pulses of light a second down to Earth's surface, and times how long it takes to return to the satellite—to within a billionth of a second. The instrument's pulse rate allows for a dense map of measurements over the ice sheet; its high precision allows scientists to determine how much an ice sheet changes over a year to within an inch.

The researchers took tracks of earlier ICESat measurements, overlaid the tracks of ICESat-2 measurements from 2019, and took data from the tens of millions of sites where the two data sets intersected. That gave them the elevation change, but to get to how much ice has been lost, the researchers developed a new model to convert volume change to mass change. The model calculated densities across the ice sheets to allow the total mass loss to be calculated.

"These first results looking at land ice confirm the consensus from other research groups, but they also let us look at the details of change in individual glaciers and ice shelves at the same time," said **Tom Neumann** [NASA's Goddard Space Flight Center—*ICESat-2 Project Scientist*].

In Antarctica, for example, the detailed measurements showed that the ice sheet is getting thicker in parts of the continent's interior as a result of increased snowfall, according to the study. But the loss of ice from the continent's margins—especially in West Antarctica and the Antarctic Peninsula—far outweighs any gains in the interior. In those places, the loss is due to warming from the ocean.

According to Smith, there was a significant amount of thinning of coastal glaciers in Greenland. The Kangerlussuaq and Jakobshavn glaciers, for example, have lost 14 to 20 ft (4 to 6 m) of elevation per year; the glacial basins have lost 16 gigatons per year and 22 gigatons per year, respectively. Warmer summer temperatures have melted ice from the surface of the glaciers and ice sheets, and in some basins the warmer ocean water erodes away the ice at their fronts.

"The new analysis reveals the ice sheets' response to changes in climate with unprecedented detail, revealing clues as to why and how the ice sheets are reacting the way they are," said co-author **Alex Gardner** [NASA/Jet Propulsion Laboratory].

The study also examined *ice shelves*—the floating masses of ice at the downstream end of glaciers. These ice shelves, which rise and fall with the tides, can be difficult to measure, said co-author **Helen Amanda Fricker** [Scripps Institution of Oceanography at the University of California San Diego]. Some of them have rough surfaces with crevasses and ridges, but the precision and high resolution of ICESat-2 allows researchers to measure overall changes.

This is one of the first times that researchers have used laser altimetry to measure loss of the floating ice shelves around Antarctica simultaneously with loss of the continent's ice sheet.

The researchers found ice shelves are losing mass in West Antarctica, where many of the continent's fastest-moving glaciers are located as well. Patterns of thinning over the ice shelves in West Antarctica show that Thwaites and Crosson ice shelves have thinned the most, an average of about 16 ft (5 m) and 10 ft (3 m) of ice per year, respectively.

Ice that melts from ice shelves doesn't raise sea levels, since it's already floating—just like an ice cube already in a full cup of water doesn't overflow the glass when it melts. But the ice shelves do provide stability for the glaciers and ice sheets behind them.

"It's like an architectural buttress that holds up a cathedral," Fricker said. "The ice shelves hold the ice sheet up. If you take away the ice shelves, or even if you thin them, you're reducing that buttressing force, so the grounded ice can flow faster."

To watch a video discussion of this topic, visit *https://svs.gsfc.nasa.gov/13600*. ■

NASA Funds Four Research Projects on COVID-19 Impacts

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

The COVID-19 pandemic changed the routines of millions of people around the world seemingly overnight. In some places, once-congested streets are now easily navigable; previously crammed sidewalks, eerily vacant.

Such widespread, rapid change in human activity is unprecedented and its effects on our planet and our lives are only just beginning to be realized. NASA's Earth Science Division is supporting the science community as it investigates the many changes this unique situation has brought to light. Through its Rapid Response and Novel Research in Earth Science (RRNES) initiative, the agency is providing funding for selected, rapid-turnaround projects that make innovative use of satellite data and other NASA resources to address the different environmental, economic, and societal impacts of the pandemic. NASA announced in April 2020 the first RRNES projects and is continuing to evaluate new project proposals.

Thus far, the agency has funded the following four RRNES projects:

Exploring Uneven Gains in Urban Air Quality

The drastic reduction of passenger vehicles on the roads has resulted in a drop in air pollution, particularly nitrogen dioxide (NO_2), in many urban areas—see **Figure**. However, according to **Susan Anenberg** and **Dan Goldberg** [both from George Washington University], initial analysis of satellite data indicates that the decrease in NO_2 concentrations across cities globally during their lockdown periods has been inconsistent. Cities in China and Italy, for example, seem to show a much greater and more abrupt decline in this type of pollution than many cities in the U.S.

"Our project will link satellite remote sensing with weather, traffic counts, and other data to shed light on why we are seeing these inconsistent effects of COVID-19 lockdowns on air quality in different cities around the world," said Goldberg.

Data like this can greatly benefit public health both now, as we navigate the current pandemic, and in the future.

"Since air pollution may be a risk factor for increased severity of COVID-19 outcomes, accurate information about air pollution levels during the COVID-19 crisis is critical to protect public health," Anenberg said. "Our project will also improve public health in the long term by advancing our understanding of how transportation

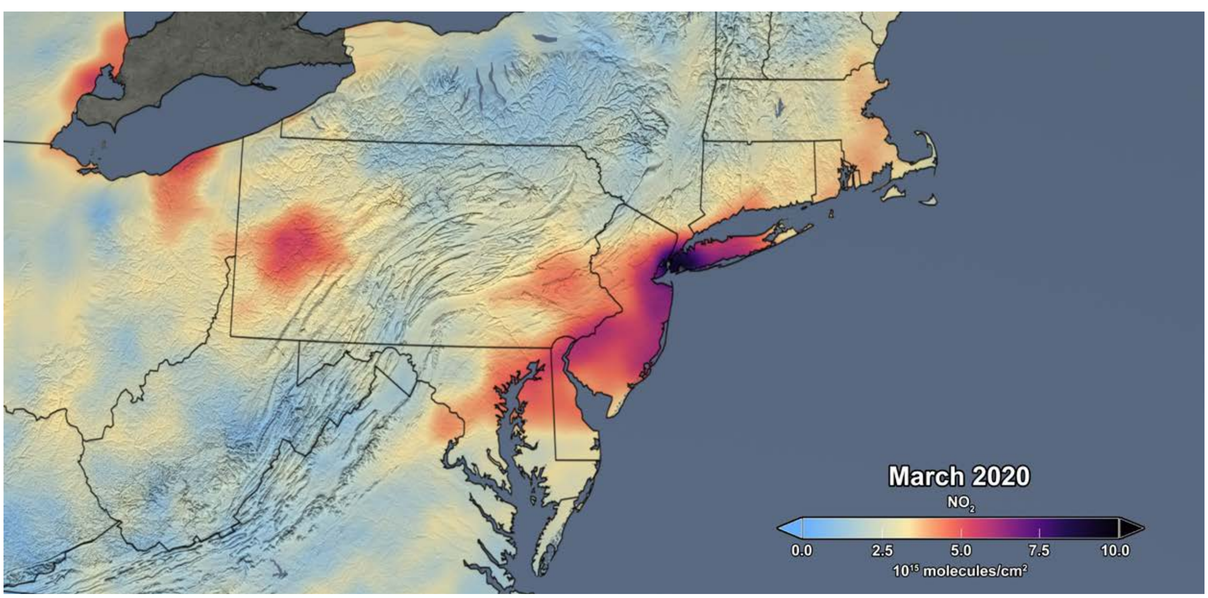

Figure. Over the past several weeks, NASA satellite measurements have revealed significant reductions in air pollution over the major metropolitan areas of the Northeast U.S. Similar reductions have been observed in other regions of the world. These recent improvements in air quality have come at a high cost, as communities grapple with widespread lockdowns and shelter-in-place orders as a result of the spread of COVID-19. Shown here, the March 2020 levels of nitrogen dioxide (NO_2) in the northeast U.S. were 30% lower on average than previous years. **Credit:** NASA's Scientific Visualization Studio policies can be designed to improve air quality most effectively and efficiently."

Impact of Air Pollution Reduction on the Atmosphere

Although satellites have observed a global decrease in some types of air pollution, including NO_2, it remains to be seen how long the reduction in harmful emissions will last and what effects these changes will have on the chemistry of the atmosphere in the future. **Kang Sun** [University at Buffalo] is developing a process that will give scientists and stakeholders a way to efficiently monitor both.

"Using a new data-driven framework that combines satellite and meteorological data, we will take NASA satellite assets one step further to quantify the reduction in emissions and its impact on air quality chemistry," said Sun.

For now, he plans to focus his research on three regions, each at different phases of the pandemic—and that have adhered to different regulations and policies in an effort to control it.

"We will focus on nitrogen oxides in the polluted regions of Jianghan Plain (which includes Wuhan) in China, Po Valley in Italy, and Southern California in the U.S.," he said. "However, the established framework can be quickly applied to other regions, time periods, and trace gases with rapid sharing of the results, algorithm, and data generated by this project."

Air Pollution Links to Water Quality

What goes into our air can also impact other parts of the Earth system, like water quality. **Maria Tzortziou** and **Brice Grunert** [both from City University of New York] are researching this connection to determine what impact the COVID-19-related declines in air pollution may have on coastal water quality in Long Island Sound, near New York City.

"Socioeconomic policy responses to the COVID-19 pandemic have resulted in a dramatic decline in atmospheric nitrogen pollution across the globe. Yet, the impacts on atmospherically deposited nitrogen and resulting changes in coastal aquatic ecology remain unknown," said Tzortziou.

In general, an overabundance of nitrogen and other chemicals and nutrients in the water can cause excessive algae growth. When the algae decompose, a process that consumes oxygen, the water is often left without enough oxygen to sustain life. In other words, these processes have a negative effect on water quality.

The reduction of atmospheric nitrogen pollution due to society's response to the pandemic provides scientists with a unique opportunity to investigate air pollution's influence on water quality.

"Using new measurements from ground-based and satellite platforms to capture changes in both atmospheric and water quality conditions, this project will help address a gap in our fundamental understanding of air-water exchange of nutrients and pollutants, and how this impacts and is impacted by environmental regulations, socioeconomic policy responses, and decision making," said Tzortziou.

Shedding (Night) Light on Pandemic Economic Impacts

In addition to environmental changes, measures to curb the spread of COVID-19 have led to a substantial shift in human activity and movement around the globe. A team of researchers led by **Miguel Román** [Universities Space Research Association—*Program Director*], who is a principal investigator of NASA's Black Marble science team, is using satellite nighttime-light data to help assess the social and economic impacts of this crisis locally to globally, and the effectiveness of containment actions, such as stay-at-home orders, taken to control the spread of the virus.

"Our research team has been analyzing images of Earth at night to decipher patterns of energy use, transportation, migration, and other economic and social activities," Román said. "Currently, there are minimal data about how different containment strategies have affected local businesses and neighborhoods, and how companies and residents are responding to preventative measures aimed at containment."

The research team will use NASA's Black Marble—a product suite that provides daily satellite-derived nighttime light data—along with population, urban infrastructure, and local pandemic response information to develop COVID-19-specific maps and data products capable of tracking these responses from the street level to the global level in near-real time.

"By tracking responses at fine spatial scales—at the subneighborhood level, for example—using NASA's Black Marble product, we seek to improve understanding of how responses to containment strategies have varied within cities and across metropolitan areas with different levels of urbanization and regulation," said Román.

This information can inform stakeholders responsible for monitoring the extent, duration, and recovery from this and future outbreaks and disasters. ■

NASA Earth Science in the News

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

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

As China's Coronavirus Shutdowns End, Air Pollutants Rise to Traditional Levels, May 30, *foxnews.com*. As economic activity resumes in China following the first wave of the coronavirus pandemic, levels of the air pollutant nitrogen dioxide (NO_2) are rising to traditional standards for the first time this year—see **Figure 1**. According to NASA's Earth Observatory reports, in February 2020 scientists using NASA and European satellites identified a significant reduction in NO_2 over the country after COVID-19 shutdown regulations took effect. With the conclusion of stringent health mandates, just three months later scientists saw the anticipated rebound.

****NASA Hires NOAA Official as New Earth Science Director**, May 10, *spacenews.com*. NASA has selected an official with the National Oceanic and Atmospheric Administration's (NOAA) satellite division to lead its Earth Science programs—a search that took more than a year to complete. **Thomas Zurbuchen** [NASA Headquarters—*Associate Administrator for the Science Mission Directorate*] announced May 5 that the agency had chosen **Karen St. Germain** as the new director of NASA's Earth Science Division. St. Germain formally started work at NASA June 8. St. Germain was the deputy assistant administrator for systems at NOAA's National Environmental Satellite, Data, and Information Service (NESDIS), which operates NOAA's fleet of weather satellites. In that role she oversaw development of NOAA's existing and planned satellites, and also led a study of next-generation architecture for weather satellites that explored the prospect of using a larger number of smaller satellites, some in nontraditional orbits. "Her enthusiasm, and the experience she has gained throughout her distinguished career, will bring great value and perspective to our critical work to learn more about our home planet," Zurbuchen said of St. Germain in a statement.

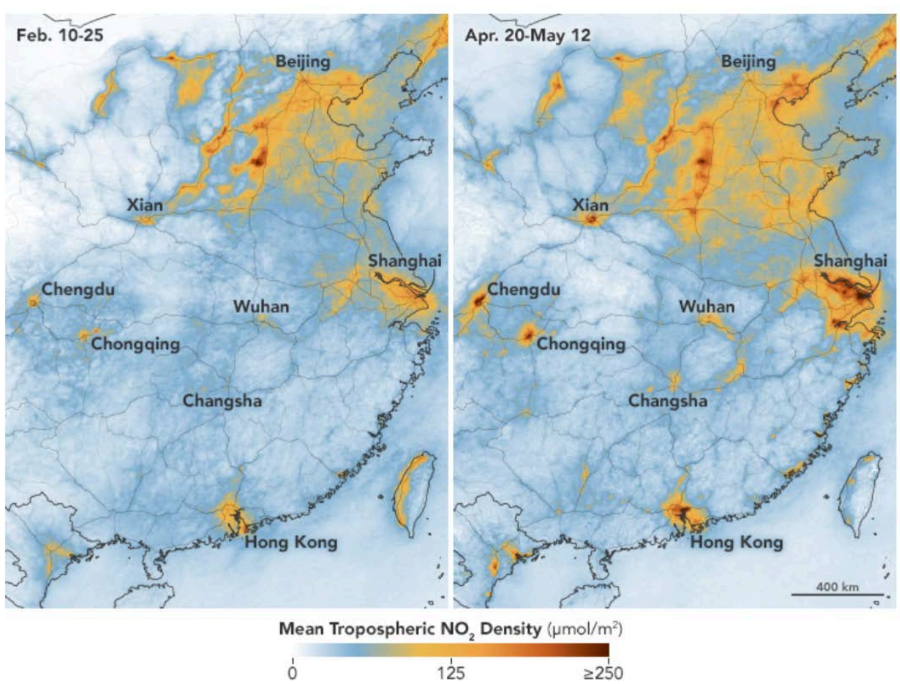

Figure 1. These maps show tropospheric NO_2 levels in central and eastern portions of China from February 10–25, 2020 (during the quarantine) and April 20 to May 12 (after restrictions were lifted). These data were collected by the Tropospheric Monitoring Instrument (TROPOMI) on the European Commission's Copernicus Sentinel-5P satellite, built by the European Space Agency. **Credit:** NASA Earth Observatory

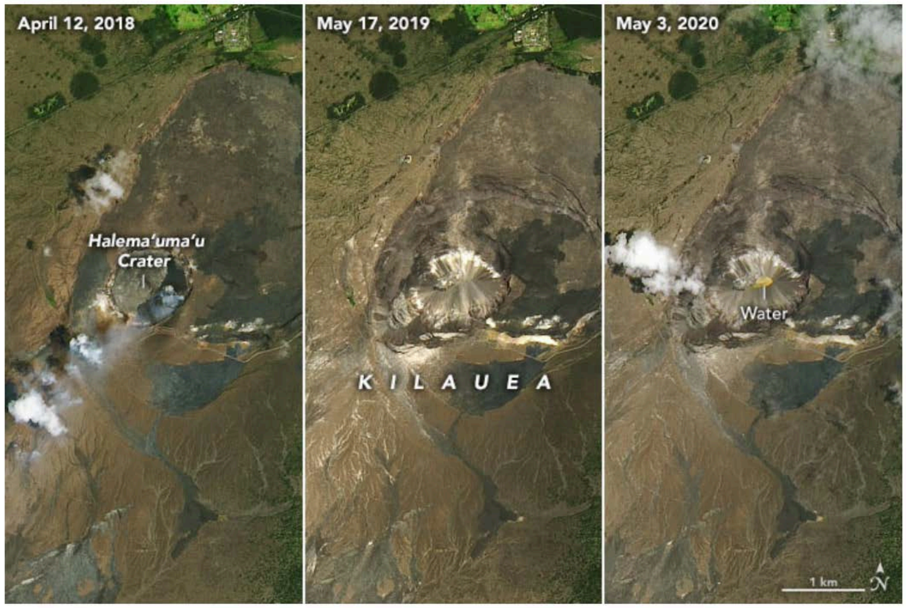

Figure 2. The sequence of satellite images above shows Halema'uma'u crater before the lava lake drained [*left*], after the caldera floor had collapsed [*middle*], and after water pooled on the crater floor for nine months [*right*]. The Operational Land Imager (OLI) on Landsat 8 acquired all three natural-color images. **Credit:** NASA's Earth Observatory

"I've learned a lot along the way, including what it takes to really deliver a capability, as well as what it means to balance the portfolio of programs to meet a broader set of objectives," St. Germain said in brief video message May 6. Maintaining balance between large and small missions is a key issue for the Earth science program. "This is a crucial time in Earth science," St. Germain said. "The Decadal Survey outlined a very ambitious vision for the Earth science enterprise, and I'm optimistic we can achieve that mission."

NASA Images Show the Huge New Lake of Water in Hawaii's Kilauea Volcano, May 12, *newsweek.com*. NASA has released images that document the growth of a water lake inside a huge crater within Hawaii's Kilauea volcano—see **Figure 2**. The lake started to form in the lowest part of the Halema'uma'u crater in July 2019 and has been rising steadily ever since, according to the space agency. This was the first time in recorded history that a water pond had appeared in Halema'uma'u. Now the body of water—which is rusty brown in color due to chemical reactions—measures up to 100 ft (~30 m) deep and has an area of roughly five football fields. Kilauea—which rises 4,190 ft (~1277 m) above Hawaii's Big Island, and makes up around 14% of its total area—is one of the world's most active volcanoes. It has been erupting on a continuous basis since 1983. Kilauea has a large summit *caldera*—a massive depression or crater formed by the collapse of a volcano into itself after an eruption. Halema'uma'u is located within the larger caldera. The NASA images show how the summit of the volcano has changed as a result of volcanic activity in recent years. Between 2010 and 2018 a large lake of lava emerged in the southeastern part of Halema'uma'u. However, this drained away during a broader eruption beginning in May 2018 that eventually covered 13 mi^2 (~34 km^2) of land in lava over several months, destroying around 700 homes. During this eruption, part of the caldera floor also collapsed, leaving a hole 1700 ft (518 m) deep—that's nearly as deep as New York City's One World Trade Center is high.

***NASA's ICESat-2 Mission Maps 16 Years of Melting Greenland and Antarctic Ice Sheets**, May 1, *scitechdaily.com*. Using the most advanced Earth-observing laser instrument NASA has ever flown in space, a team of scientists led by the University of Washington has made precise measurements of how the Greenland and Antarctic ice sheets have changed over the past 16 years. In a new study published in the journal *Science* on April 30, scientists found the net loss of ice from Antarctica, along with Greenland's shrinking ice sheet, has been responsible for 0.55 in (14 mm) of sea level rise to the global ocean since 2003. The findings come from the Ice, Cloud and land Elevation Satellite-2 (ICESat-2), which was launched into orbit in fall 2018 and then began taking detailed global elevation measurements, including over Earth's frozen regions. By comparing the new data with measurements taken by the original ICESat from 2003 to 2009, researchers have generated a comprehensive portrait of the complexities of ice sheet change—and insights into the future of Greenland and Antarctica. "If you watch a glacier or ice sheet for a month, or a year, you're not going to learn much about what the climate is doing to it," said glaciologist and lead author **Benjamin Smith** [University of Washington]. However, "We now have a 16-year span between ICESat and ICESat-2 and can be much more confident that the changes we're seeing in the ice have to do with the long-term changes in the climate. And ICESat-2 is a really remarkable tool for making these measurements. We're seeing high-quality measurements that carpet both ice sheets, which let us make a detailed and precise comparison with the ICESat data." Previous studies of ice loss or gain often analyze data from multiple satellites and airborne missions. The new study takes a single type of measurement—height as measured by an instrument that bounces laser pulses off the ice surface—providing the most detailed and accurate picture of ice sheet change to date. The researchers took tracks of ICESat measurements and overlaid the denser tracks of ICESat-2 measurements from 2019. Where the two data sets intersected—tens of millions of sites—they ran the data through computer programs that accounted for the snow density and other factors, and then calculated the mass of ice lost or gained. "The new analysis reveals the ice sheets' response to changes in climate with unprecedented detail, revealing clues as to why and how the ice sheets are reacting the way they are", said glaciologist and co-author **Alex Gardner** [NASA/Jet Propulsion Laboratory]. The study found that Greenland's ice sheet lost an average of 200 gigatons of ice per year, and Antarctica's ice sheet lost an average of 118 gigatons of ice per year—see Figure in the News story on page 26. One gigaton of ice is enough to fill 400,000 Olympic-sized swimming pools.

* See news story in this issue.

** For more information, see the Editor's Corner of this issue.

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

NOTE: *The Earth Observer* has temporarily suspended publication of its *Science Calendars*. In response to the ongoing COVID-19 pandemic and mandated social distancing most all NASA and International in-person meetings that had been scheduled for the next few months have either been cancelled or postponed. Some groups are rescheduling smaller online events; others are rescheduling in-person meetings later this year or in 2021. However, as of this writing the details are still rapidly evolving making it difficult to print a calendar at this time. We will resume publishing the calendar when the schedule becomes more settled.

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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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