Over Thirty Years Reporting on NASA's Earth Science Program

The Earth Observer

National Aeronautics and Space Administration

November – December 2021. Volume 33, Issue 6

The Editor's Corner

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As reported in our last issue, Landsat 9 launched September 27, 2021, and is now completing its on-orbit checkout period.[1] The joint NASA–USGS Landsat 9 mission carries two instruments that capture land and coastal imagery: the Operational Land Imager 2 (OLI-2), which detects visible, near-infrared, and shortwave-infrared light in nine spectral bands; and the Thermal Infrared Sensor 2 (TIRS-2), which detects thermal radiation in two bands.[2] These instruments will provide Landsat 9 users with essential information about crop health, irrigation use, water quality, wildfire severity, deforestation, glacial retreat, urban expansion, and more.

After activating and testing the major observatory subsystems, the OLI-2 and TIRS-2 sensors were turned on for a three-week outgassing period. The initial assessment shows excellent performance of the Landsat 9 sensors. USGS will begin distributing products after the on-orbit checkout, currently planned for completion in January 2022. All image products will be available at no cost to users. The images below show examples of some of the first images returned from Landsat 9.

On October 28, 2021, the Suomi National Polar-orbiting Platform (Suomi NPP) celebrated the tenth anniversary of its launch. Suomi NPP was conceived as a bridge mission between many of the NASA Earth Observing System (EOS) capabilities and what became the NOAA Joint Polar Satellite System (JPSS). The satellite, a joint venture between NASA and NOAA,[3] was named to honor Verner Suomi, a pioneer in early meteorological satellite observations. It carries five Earth-observing instruments (VIIRS, ATMS, CrIS, OMPS, and CERES) that make measurements similar (or in the case of CERES, identical) to several instruments on the three EOS flagship missions (Terra, Aqua, Aura).

JPSS-1 launched in 2017 and is now known as NOAA-20; three more JPSS launches are planned over the next decade, continuing these vital weather and environmental observations into the 2030s. JPSS-2, to be designated NOAA-21 after a successful launch and checkout, is scheduled for launch in September 2022. The launches of JPSS-3 and JPSS-4 are planned on successive five-year periods after the JPSS-2 launch.

To learn about Suomi NPP's achievements, please see the video "A Decade of Discovery for Suomi NPP" (*www.youtube.com/watch?v=Oonwt7YG0AQ*). Among Suomi NPP's unique capabilities, the VIIRS Day-Night Band has allowed for

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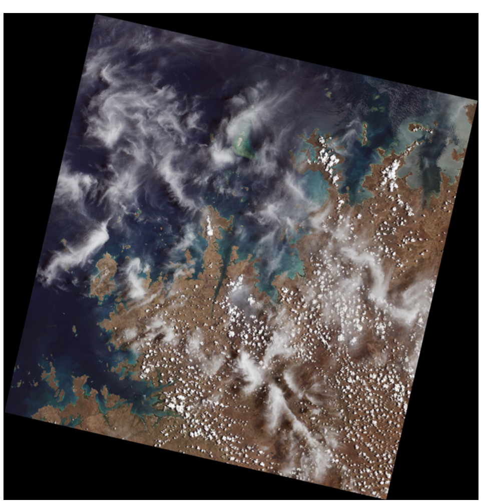
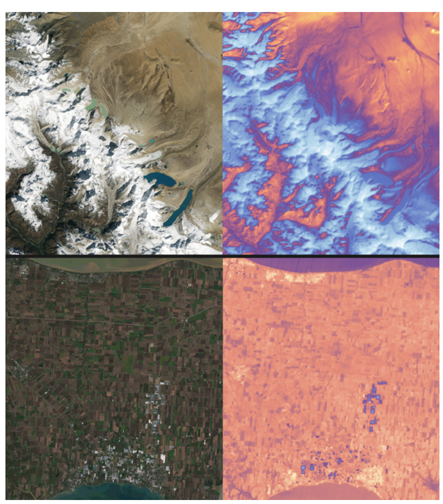
[1] See the "Editor's Corner" of the September–October 2021 issue of *The Earth Observer* [**Volume 33**, **Issue 5**, p. 1] to learn more about the Landsat 9 launch.
[2] To learn more about Landsat 9, see "The Legacy Continues: Landsat 9 Moves Landsat Toward Golden Milestone," in the July–August 2021 issue of *The Earth Observer* [**Volume 33**, **Issue 3**, pp. 4–14—*go.nasa.gov/3GZ3ATW*].
[3] To learn more about Suomi NPP, visit *go.nasa.gov/3Eho48N*.





October 31, 2021, the first Landsat 9 image was acquired over the Kimberley Coast of northwestern Australia [*left*]. Through swirling clouds, the OLI-2 image shows the coastline and mangrove forests of this remote area, along with the hues of the Indian Ocean. On subsequent orbits, Landsat 9 imaged the Himalayas near Kathmandu Nepal [*upper right images*] and southern Ontario [*lower right images*]. Each image pair shows a visible wavelength composite from OLI-2 [*middle column*] alongside a surface temperature image from TIRS-2 [*right column*]. The bright, cold Himalayan glaciers terminate in proglacial lakes and contrast with the warmer land surface of the Tibetan Plateau [*top row*]. The Ontario image shows bright, cool greenhouses isolated within the warmer land surface [*bottom row*]. **Image credit:** NASA/USGS

In This Issue

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

significant advances in our ability to monitor the Earth at night.[4] Not only are these images of Earth at night signatures of Suomi NPP, but they are used for a variety of applications, e.g., tracking power outages after storms and tracking human activities at night such as highway travel, sea travel, and flares from gas wells.

In addition to operational uses, selected science products from Suomi NPP and NOAA-20 are being produced by NASA to continue many critical EOS data records using, to the extent possible, consistent algorithms as well as radiative transfer models and ancillary data sources. This enables the production of unified multidecadal data records that are key to understanding and quantifying global change.

December 15, 2021, marked the fifth anniversary of the launch of the Cyclone Global Navigation Satellite System (CYGNSS) constellation of eight microsatellites. Following an initial on-orbit commissioning phase, the constellation has been providing continuous science measurements since April 2017. Each CYGNSS spacecraft carries a four-channel radar-receiver that receives both direct and surface-reflected GPS satellite signals. The received power is used to compute scattering cross section.

Over ocean, algorithms have been developed to convert scattering cross section into estimates of surface roughness, near-surface wind speed, sea surface height, and, most recently, microplastic concentration. Over land, estimates of near-surface soil moisture and imaging of inland water body extent are possible. Due to the low microwave frequencies at which GPS operates, reflected signals are able to penetrate through heavy precipitation. The density and revisit time of sampling that results from the low inclination constellation makes possible the detection of tropical cyclone intensification, the diurnal cycle of tropical winds, and day-to-day changes in flood inundation. The frequent measurement of winds in and near tropical cyclones has been shown to improve the ability to model inner core structure and forecast intensities. Similarly, sub-daily measurements of soil moisture dynamics on a global basis have improved global land surface hydrology models.

CYGNSS completed its initial 24-month phase of science operations in 2019 and is now in its extended mission phase, with continued operation supported through at least 2023. *The Earth Observer* plans a feature on the accomplishments of CYGNSS in its next issue.

Looking to the future, on November 5, 2021, NASA Headquarters announced that the Investigation of Convective Updrafts (INCUS) had been chosen from among 12 proposals submitted in March 2021 in response to the Earth Venture Mission–3 (EVM-3) solicitation.[5] Expected to launch in 2027, INCUS will be a collection of three SmallSats flying in tight coordination that will allow researchers to study the behavior of convective storms within the tropics. The vertical

[4] Examples of DNB images appear in *Earth at Night: Our Planet in Brilliant Darkness*, a 2019 NASA publication, which can be downloaded in various formats at *go.nasa.gov/2LM1wEy.*

[5] The Venture Class Program element consists of new science-driven, competitively selected, low-cost innovative Earth science missions to enhance the capability for understanding the current state of the Earth system and enable continual improvement in the prediction of future changes.

transport of air and water vapor in thunderstorms, known as *convective mass flux* (CMF), plays a critical role in the weather and climate system through its influence on storm intensity, precipitation rates, upper tropospheric moistening, high-cloud feedbacks, and the large-scale circulation. INCUS will enable systematic CMF measurements over the full range of tropical environmental conditions, which will improve the representation of storm intensity and constrain high-cloud feedbacks to improve weather and climate models.

INCUS is a Class-D mission comprised of three RainCube-heritage K_a-band five-beam scanning radars, each of which is housed by a SmallSat platform. The satellites will be spaced to provide three different time intervals between observations (30, 90, and 120 seconds) over which profiles of radar reflectivity are observed. The middle SmallSat will also carry a single TEMPEST-D-heritage cross-track-scanning passive microwave radiometer with four channels between 150 and 190 GHz.[6] This will allow for an assessment of the properties of high anvil clouds. Through its novel measurements of time-differenced profiles of radar reflectivity, INCUS allows the first systematic investigation of the rapidly evolving CMF within tropical convective storms.

Susan van den Heever [Colorado State University] is the INCUS Principal Investigator. Major support comes from JPL, along with participation from personnel at Stony Brook University, Texas A&M, City College of New York, MSFC, and GSFC. Blue Canyon Technologies and Tendeg LLC, both in Colorado, will provide key satellite system components. The mission is expected to cost approximately $177M, not including launch costs. NASA will select a launch provider at a later date. My congratulations to Susan and the entire INCUS team.

Meanwhile, after delays due to the pandemic, the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission is back on track and working toward a scheduled January 2024 launch. PACE's primary instrument—the hyperspectral scanning Ocean Color Instrument (OCI)—has begun flight unit assembly and testing, with delivery of the observatory planned for mid-2022. The flight units for PACE's other two instruments are also awaiting integration onto the spacecraft. The Spectropolarimeter for Planetary Exploration (SPEXone), a multi-angle polarimeter being built and overseen by the SRON Netherlands Institute for Space Research and Airbus Defence and Space Netherlands, was delivered to the mission in early 2021. The Hyper-Angular Rainbow Polarimeter (HARP2), another multi-angle polarimeter being built by the University of Maryland, Baltimore County's Earth and Space Institute is nearing completion with delivery to GSFC expected in the first quarter of 2022. These two instruments will significantly improve aerosol and hydrosol characterizations and provide opportunities for novel ocean color atmospheric correction.

The competitively-selected PACE Science and Application Team continues to work with the Project to advance the scientific capabilities of the mission. The PACE Applications Program organized and hosted two virtual meetings in 2021: a Water Quality Focus session in July and the second Applications Workshop in September. Both meetings provided opportunities to initiate interdisciplinary dialogues focused on PACE and how its anticipated data products could support a variety of societal needs. Turn to page 14 of this issue to read about the second PACE Applications Workshop.

NASA's Earth observing fleet produces large data volumes daily and more missions—with even greater data volumes—are scheduled to join the fleet in the next decade. The need to manage data so that users can easily access and make use of them has never been greater. In our last issue we reported on plans for Open-Source Science at NASA.[7] In this issue we have a related feature article that describes NASA's Interagency Implementation and Advanced Concepts Team (IMPACT), which seeks to prototype concepts for optimizing the use of Earth science data. This is an interdisciplinary team within NASA's Earth Science Data Systems division that will work to maximize the effectiveness and efficiency of Earth science data management and stewardship. Turn to page 4 to learn more about IMPACT.

Finally, NASA participated in the U.S. Center (organized by the U.S. Department of State) at the recent COP26 meeting in Glasgow, Scotland. As has been the case at previous COP meetings, the NASA Hyperwall was one of the main attractions at the U.S. Center. There were several presentations throughout the conference (with both in-person and virtual presenters) that highlighted NASA climate programs and relevant scientific research. Turn to page 10 of this issue to read about NASA's involvement in COP26 and to view photos taken at the event. ■

[6] To learn about the launch of RainCube and TEMPEST-D, see the "Editor's Corner" of the July–August 2018 issue of *The Earth Observer* [**Volume 30**, **Issue 4**, pp. 2–3]. To watch a video about these two pioneering CubeSat missions, see "Into a Shoebox: The Incredible Journey of RainCube and TEMPEST-D," (*www.youtube.com/watch?v=_lI4rjL4yYw*).

[7] To learn more, see "Open Source Science: The NASA Earth Science Perspective," in the September–October 2021 issue of *The Earth Observer* [**Volume 33**, **Issue 5**, pp. 5–9—*go.nasa.gov/3ElvLM9*].

List of undefined acronyms used in the Editorial and/or Table of Contents on page 13

Getting Maximum IMPACT from Earth Science Data

Derek Koehl, NASA's Marshall Space Flight Center, derek.a.koehl@nasa.gov

What is IMPACT?

NASA's Earth Science Data Systems (ESDS) Program's Interagency Implementation and Advanced Concepts Team (IMPACT) was formed to meet the need for a multidisciplinary team of Earth and computer scientists that can leverage advanced data management concepts along with *machine learning* (ML) and *artificial intelligence* (AI) to help researchers utilize the ever-increasing volume of Earth observation data. In addition to ML and AI implementations, IMPACT, which is based out of Marshall Space Flight Center (MSFC) and located at the University of Alabama in Huntsville (UAH), also develops and models best practices for data management. IMPACT grew out of MSFC's Earth Science Branch's Data Science group in 2018 to support several ESDS Program needs and objectives.

IMPACT is driven by three focus areas: innovation, collaboration, and new technology adoption.

IMPACT is driven by three focus areas: innovation, collaboration, and new technology adoption. Central to all of IMPACT's initiatives is the drive to champion innovation. Complex problems often require conceptualization of creative new solutions. The members of the IMPACT Team work to improve existing processes and develop best practices that maximize the effectiveness and efficiency of existing Earth science data-management processes and stewardship. IMPACT values the collaborations that arise from strategic partnerships and how these collaborations help bring NASA's Earth observations and data products to other agencies through services, tools, and software. IMPACT's efforts broaden Earth science data use and increase non-NASA use of NASA data. The team members understand that applying new technology includes both benefits and risks. Therefore, the team rapidly prototypes and tests the feasibility of the latest technical and management concepts in order to mitigate organizational risk. New capabilities are developed, proven, and then infused across the ESDS Program and, by extension, across the Earth Science Division (ESD) of NASA's Science Mission Directorate (SMD).

A Collaboration at Its Core

The engine that drives IMPACT is a tight collaboration between NASA and UAH. The collaboration integrates the efforts of NASA civil servants, UAH researchers, and specialized staffing contractors. The program has two principal investigators who lead the investigators working at their respective organizations: **Rahul Ramachandran** [MSFC] and **Sundar Christopher** [UAH, Earth System Science Center].

Within IMPACT, team members function as a seamless whole across four core team groupings as they work to operationalize IMPACT's focus areas. These team groupings are Public–Private Partnerships, Informatics, Machine Learning, and the Satellite Needs Working Group (SNWG).

Public–Private Partnerships Team

Central to the IMPACT team's commitment to collaboration is the Public–Private Partnerships Team led by **Elizabeth Fancher** [MSFC]. A primary focus of this team is to establish Space Act Agreements (SAA),[1] which create a distinct type of nonprocurement business relationship that furthers the data management and data development efforts of ESDS. For example, one SAA with Amazon Web Services (AWS) supports a collaboration on cloud-based discovery, access, and use of high-value science datasets in NASA's Earth Observing System Data and Information System (EOSDIS) collection. The AWS partnership features two primary activities. The first is a design and development sandbox organized through the AWS Open Data Program that serves as a technology showcase and demonstrates ESDS data storage, archive, and use efforts, all using the AWS commercial cloud. This activity supports the storage of publicly

[1] For a list of current Space Act Agreements, see *go.nasa.gov/2ZBRDnh.*

available, high-value, cloud-optimized datasets. Several EOSDIS datasets are available through the Registry of Open Data on AWS (*registry.opendata.aws/collab/nasa*). The second activity of the NASA–AWS SAA partnership is the provision of AWS credits for workshops that advance access and use of NASA data on AWS.

Informatics Team

Led by **Kaylin Bugbee** and **Aaron Kaulfus** [both at MSFC] along with **Deborah Smith** and **Jeanné le Roux** [both at UAH], the Informatics Team works to generate, repair, improve, care for, document, and update NASA's scientific metadata and data to ensure these valuable assets are available today and for the scientists and decision makers of the future. The team helps to make NASA's data systems resilient and maintainable, while also enabling open science by reinforcing data transparency, reproducibility, and open access.[2] The team fills gaps between the domain-specific informatics practitioners and the broader needs of collaboration across the sciences. They also collaborate with other informatics teams across the six NASA ESD focus areas.[3] Specifically, the team seeks to enable the care of NASA data and information by making it easier for data stewards to actively ensure data discovery and usability. For example, Analysis and Review of the Common Metadata Repository (CMR) [ARC] group has developed a tool to automatically assess metadata quality.[4] The team also works to proactively develop, promote, and maintain information best practices. This includes cultivating communities of practice around improved metadata quality practices as well as the Airborne Data Management Group's work in facilitating improved and more descriptive data management plans for airborne campaigns. Through these efforts, the team strives to ensure consistency and scalability by promoting effective solutions to common data-related problems.

The IMPACT Informatics Team works to generate, repair, improve, care for, document, and update NASA's scientific metadata and data to ensure these valuable assets are available today and for the scientists and decision makers of the future.

Machine Learning Team

Led by **Manil Maskey** and **Brian Freitag** [both at MSFC] and **Iksha Gurung** [UAH], the IMPACT Machine Learning Team works to encourage the use of applied AI and ML to answer questions in Earth science. The team advertises and supports the usability of ML in NASA's SMD by incorporating ML into different stages of the data lifecycle to improve functionality and operations. The team builds reusable tools, pipelines, and labeled datasets, all of which promote an open approach to ML in the Earth sciences and provides an archive of labeled data for scientists to leverage in building ML applications. They also support ML efforts in ESDS by tracking new developments in the areas of AI and ML. As part of this focus, the team applies ML perspectives to analytics architecture designs. The team also strives to utilize the full capacity of ML advances in high-end computing and cloud computing in order to achieve SMD's research goals.

Satellite Needs Working Group Team

Led by **Cerese Albers** and **Andrew Molthan** [both at MSFC] along with **Katrina Virts** [UAH], the IMPACT Satellite Needs Working Group (SNWG) Team works in coordination with the larger SNWG initiative of the U.S. Group on Earth Observations. The team serves as a data liaison between EOSDIS and other federal agency activities. Through uncovering and communicating existing and future data gaps to NASA, the team works to better inform current and future mission decisions. Data continuity is a primary concern for participating SNWG agencies; thus, the platforms developed to support participating agencies discussed above address these needs. The inclusion of data continuity information not only allows users to analyze

[2] To learn more, see "Open-Source Science: The NASA Earth Science Perspective," in the September–October 2021 issue of *The Earth Observer* [**Volume 33**, **Issue 5**, pp. 5–9—*go.nasa.gov/3ElvLM9*].

[3] The six focus areas of the ESD's Research and Analysis Program are Atmospheric Composition, Weather, Carbon Cycle and Ecosystems, Water and Energy Cycle, Climate Variability and Change, and Earth Surface and Interior. Learn more at *go.nasa.gov/3lKPX2D*.

[4] To learn more about CMR, see *go.nasa.gov/3Eb3K9N*.

temporal trends within similar data sources but it also allows users to identify potential future data gaps for mission planning. Such planning is critically important to the operational needs of participating agencies.

Lowering Barriers through Open Data Systems

The IMPACT mission aims to expand open science through innovation, partnerships, and technology. This mission is embodied in four key objectives:

- to create forward-looking data curation policies, tools, services, and documentation by envisioning new ways to lower barriers to access and use data and information;
- to lead the development of innovative open data systems to support rapidly evolving data-production and -management needs;
- to harness technology advances in data and information systems to expand community impact; and
- to develop and strengthen partnerships for knowledge exchange and infusion of new technology to solve challenging problems.

The IMPACT mission aims to expand open science through innovation, partnerships, and technology.

These IMPACT objectives overlap with and complement those of ESDS.[5] For example, the first IMPACT mission objective listed is complementary with the ESDS goal of setting the standard for efficient production and stewardship of science-quality data. An example of this is *pyQuARC*, a python code package that streamlines the process of assessing the quality of metadata by performing automated quality checks on metadata. This tool was developed as part of the Informatics Team's ARC project, which is tasked with assessing NASA's metadata records in the CMR for correctness, completeness, and consistency. In addition to basic validation checks (e.g., adherence to the metadata schema, controlled vocabularies, and link checking), pyQuARC flags opportunities to improve or add contextual metadata information in order to help the user connect to, access, and better understand relevant data products.

The Catalog of Archived Suborbital Earth Science Investigations (CASEI; *impact.earthdata.nasa.gov/casei*) is another example of how IMPACT lowers barriers to data and information—see **Figure 1** on page 7. CASEI was developed by the Airborne Data Management Group within the Informatics Team. The catalog provides quick access to detailed information about historical and ongoing airborne and field investigations both funded by NASA and those in which NASA participated.[6] CASEI is a unique inventory that provides intensively curated information about the context, research motivation, funding, and details of nonsatellite instruments and platforms. Information about important events and observations are included, along with links to relevant data products, all in a single intuitive and highly interconnected web-based user interface.

The ESDS goal of advancing open science data systems for the next generation of missions, data sources, and user needs is reflected in IMPACT's second objective listed above. A demonstration of this is the Algorithm Publication Tool (APT), a web-based application for streamlining authoring, management, and discovery of algorithm theoretical basis documents (ATBDs), which are important for understanding and properly using data. Data users can easily search and discover ATBDs using the APT's centralized repository. Furthermore, the APT team has worked with the American Geophysical Union's *Earth and Space Science (ESS)* journal editor to provide a means for ATBD authors to easily select ESS journal publication for their ATBDs. Approved ATBD authors complete an online form to write, edit, review, and prepare ATBDs for publication, either within APT or in the ESS journal.

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[5] The four ESDS goals are listed at *earthdata.nasa.gov/esds.*

[6] To learn more about NASA's airborne investigations, see "Flying in the 'Gap' Between Earth and Space: NASA's Airborne Science Program," in the September–October 2020 issue of *The Earth Observer* [**Volume 32**, **Issue 5**, pp. 4–14—*go.nasa.gov/2KSPTy5*].

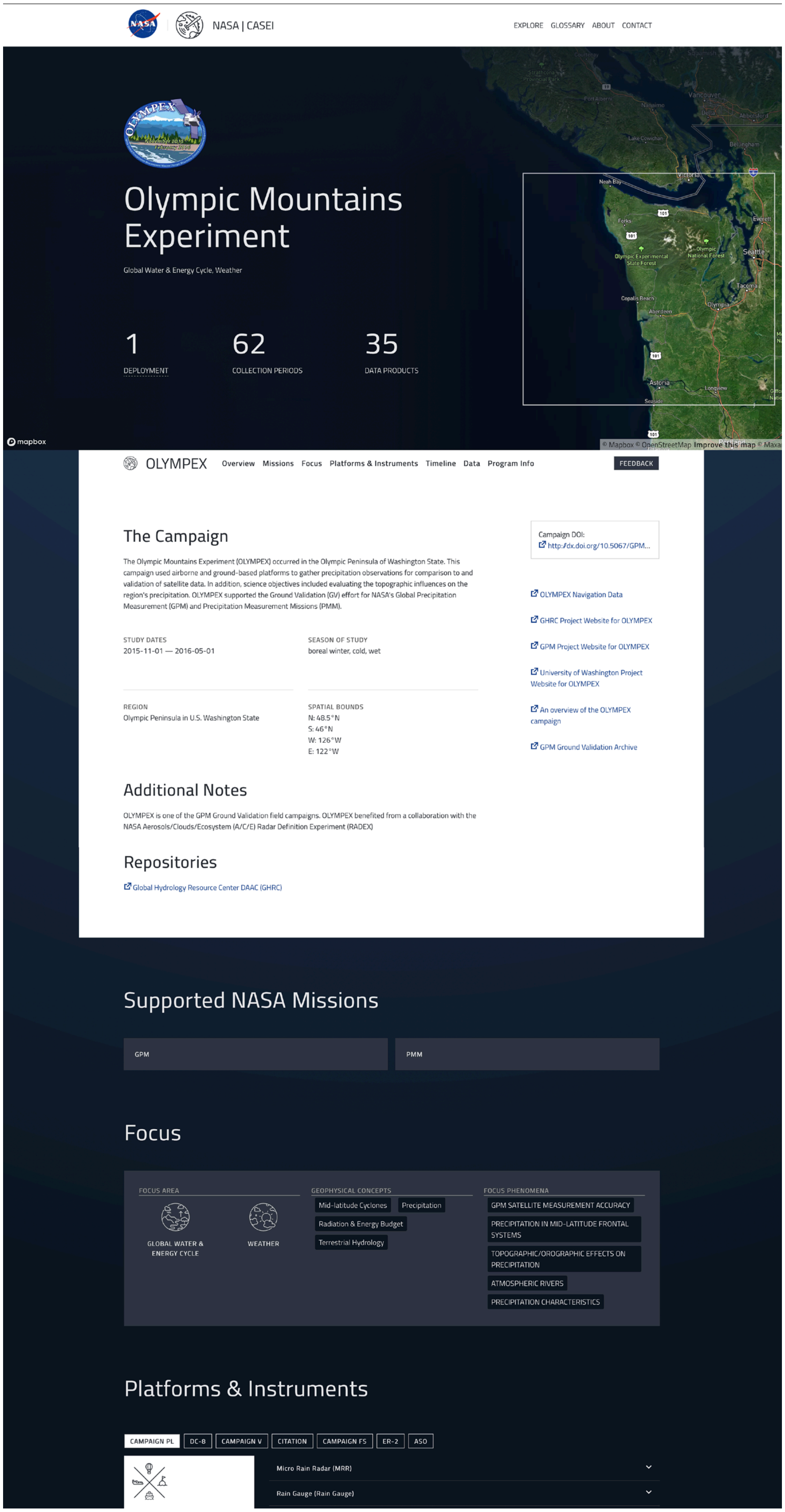

Figure 1. CASEI provides quick access to detailed information about historical and ongoing airborne and field investigations, both those funded by NASA and those in which NASA participated. Shown here is the landing page for the Olympic Mountain Experiment, which shows the CASEI user interface. **Photo credit:** IMPACT

Harnessing Technology to Advance Open Science

IMPACT emphasizes the ESDS priority to expand community impact by leading research and development of technology for management and analysis of complex Earth science data in order to harness technology advances in data and information systems. A few examples follow.

Competition on Flood Detection

IMPACT collaborated with the Geoscience and Remote Sensing Society to organize the Emerging Techniques in Computational Intelligence's 2021 Competition on Flood Detection. Participants developed supervised learning algorithms to identify flood pixels after training their algorithms against a training set of synthetic aperture radar (SAR) images—see **Figure 2**. The Machine Learning Team assembled a group of students from across the world to label the dataset that was provided by NASA's Alaska Satellite Facility (ASF) Distributed Active Archive Center (DAAC).[7] Subject-matter experts worked closely with the students to generate the flood-extent datasets. Such collaborative efforts promote open science.

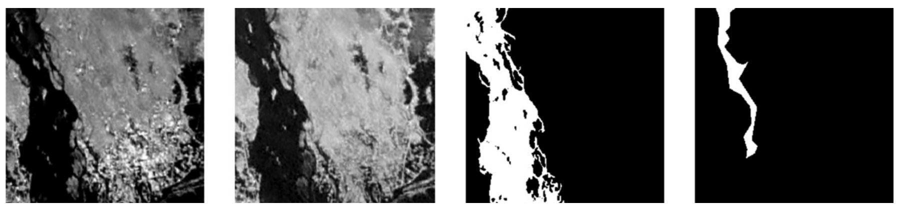

Figure 2. [*Left to right*] Two images from the European Space Agency's Copernicus Sentinel-1 mission's synthetic aperture radar (SAR) and two reference data images marking flood areal extent [*middle right*] and baseline water body [*far right*]. These images were among those used to "train" the supervised learning algorithms that students participating in the Emerging Techniques in Computational Intelligence's 2021 Flood Extent Detection Competition used to identify flooded pixels. **Image credit:** IMPACT

Tagging Images for ML

ML requires trustworthy data for training purposes. To date, the only way to develop such training sets is still human-labor intensive, and so an obvious target for IMPACT.

ImageLabeler is an example of IMPACT's commitment to expanding the use of advanced technology (*go.nasa.gov/31cKUkq*). It is an open-source, web-based tool that allows users to create tagged images for use in training image-based ML models for Earth science phenomena. The ImageLabeler supports GeoTIFFs and shapefiles along with the Web Map Service Interface Standard and allows researchers to draw bounding boxes over images. ImageLabeler provides researchers with existing training sets and allows for creating new training sets. Though initially built for use in Earth science contexts, the images loaded into ImageLabeler do not need to be of an Earth science origin or intended for Earth science applications. ImageLabeler can be modified and deployed by researchers for ML models in any field to create and manage labelled image datasets.

Handling Large Data Volumes

IMPACT works to leverage the strengths of global Earth science communities to advance open science as part of its objective of developing and strengthening partnerships for knowledge exchange and the implementation of new technology to solve hard problems.

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For example, before embarking on a scientific study related to particular phenomena, like wildfires, scientists need to collect numerous instances of these phenomena. Locating these in a tool such as NASA Worldview (*go.nasa.gov/3pb0xRt*) requires searching through 197 million square miles of daily satellite imagery across more than

[7] EOSDIS is designed as a distributed data system. The ASF is one of 12 DAACs located throughout the U.S. Learn more about ASF and the other DAACs at *go.nasa.gov/3ID12N5*.

20 years of data.[8] Such an effort can produce a valuable trove of data, but the act of manually searching the data is cumbersome and laborious. Making large amounts of data more discoverable and usable for specific parameter extraction is a hard problem. To tackle this problem, IMPACT embraced an open science approach and partnered with the SpaceML initiative (*spaceml.org*), an international AI accelerator for citizen scientists and a branch of the NASA-funded Frontier Development Lab (FDL).[9] This collaborative partnership with SpaceML envisions a generalizable package of ML operations, components, and workflows that can be utilized not only by Earth science tools and applications such as Worldview, but also by other teams working on datasets ranging from the Hubble Space Telescope to the NASA Solar Dynamics Observatory. Users would not need to understand programming or even ML to benefit from ML operations (MLOps)—see **Figure 3**. The result of this effort is a set of open-science tools that simplify the use of NASA's Earth science archive for ML.

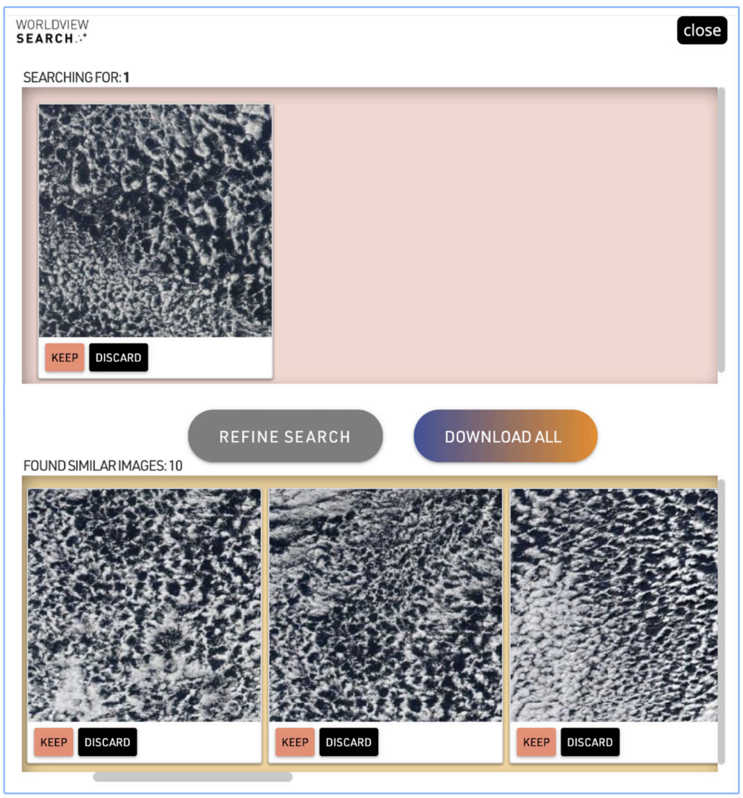

Figure 3. Shown here is a search for cloud images with similar features within Worldview using the MLOps prototype, which seeks to automate the laborious task of searching through Worldview's database of more than 20 years of satellite imagery to collect data. Applications are also envisioned for areas outside Earth science, e.g., Hubble Space Telescope and Solar Dynamics Observatory image analyses. **Image credit:** IMPACT

An IMPACT-ful Future

Rahul Ramachandran described the accomplishments of IMPACT as follows: "Even though IMPACT is a relatively new element within the ESDS program, it has made significant contributions to helping the program move towards important overarching goals. In the coming years, IMPACT will continue to expand open-source science through innovation, partnerships, and technology while fostering a culture of collaboration and innovaton within the ESDS program."

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—Rahul Ramachandran

[8] To learn more about NASA's Worldview's capabilities, see "NASA's Worldview Places Nearly 20 Years of Daily Global MODIS Imagery at Your Fingertips," in the July–August 2018 issue of *The Earth Observer* [**Volume 30**, **Issue 4**, pp. 4–8—*go.nasa.gov/3lkK3Vv*].

[9] FDL USA is a public–private partnership between NASA, the Search for Extraterrestrial Intelligence (SETI) Institute, Trillium Technologies, and leaders in commercial AI, space exploration, and Earth science.

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NASA Participates in United Nations Climate Change Conference

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Introduction

The drive to bring the nations of the world together to address responses to climate change began in earnest with the United Nations Framework Convention on Climate Change (UNFCCC), an environmental agreement, or *protocol*, initially signed by 154 states at the UN Conference on Environment and Development (a.k.a., the Rio Earth Summit), held in Rio de Janeiro, Brazil, in 1992. The UNFCCC was formally ratified in 1994 with a commitment by the signatories to prevent "dangerous human interference with the climate system."

Photo 1. The NASA Hyperwall [*center*] was the main attraction at the U.S. Center at COP26, held in Glasgow, Scotland. **Photo credit:** NASA

The UNFCCC established the Conference of the Parties (COP) as its supreme decision-making body. All parties to the UNFCCC—which today has grown to 197 (encompassing almost all the nations of the world!)—have representation at COP meetings, which occur annually (unless the parties decide otherwise) to assess progress in dealing with climate change. The idea is that convening meetings on a regular basis allows the details of the agreement to evolve as new scientific information becomes available. While there have been numerous agreements enacted by COP over the past few decades,[1] two are most widely known and significant. The first was the Kyoto Protocol, which was signed in 1997, ran from 2005 to 2020, and was the first implementation of the UNFCCC agreement. The second is the Paris Agreement, which was signed in 2015, entered into force in 2016, and essentially supersedes the Kyoto Protocol.

COP26 took place in Glasgow, Scotland October 31–November 12, 2021. This most recent COP summit brought the parties together to accelerate action towards the goals of the Paris Agreement and the UNFCCC.[2]

The U.S. Center

The hub for learning about U.S. climate actions at COP meetings is the U.S. Center, which is organized each year by the U.S. Department of State. Given the reality of an ongoing pandemic, the U.S. Center at COP26 featured in-person and virtual events. These events were intended to offer a sampling of the actors and actions that are playing a role in combating the climate crisis as it is made manifest in the U.S.

A full schedule for the U.S. Center at COP26 can be found at *www.state.gov/cop-26/schedule-and-events*. All U.S. Center events were streamed live and can be viewed at *www.youtube.com/user/TheUSCenter*.

NASA's Participation in the U.S. Center

From its inception, NASA has been making observations of the "blue marble" that we call home. With its fleet of Earth-observing satellites, aircraft and ground observations, and computer-modeling capabilities, the agency is a world leader in providing information on the state of Earth's climate and has thus been a longtime participant at the U.S. Center during COP. As has been the case at recent COP meetings, the NASA *Hyperwall*—a video wall capable of displaying multiple high-definition data visualizations and/or images simultaneously across an arrangement of screens—was the main attraction at the U.S. Center for COP26—see **Photo 1**.

[1] Other agreements enacted by COP include the Bali Action Plan (2007), the Copenhagen Accord (2009), the Cancún agreements (2010), and the Durban Platform for Enhanced Action (2012). Essentially, these were updates to the Kyoto Protocol.

[2] To learn more, visit *unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement*.

COP26 was the first event attended in person by staff from NASA's Science Support Office (SSO) since March 2020, when COVID-19 bought an abrupt end to in-person participation in conferences.[3] As they have in years past, the SSO provided technical and visualization support for the NASA presenters—this time both virtual and in person at the Hyperwall. The presentations highlighted key NASA climate programs and relevant scientific research.

The remainder of this section gives more detail on the NASA presentations given during COP26.

Presentation from NASA Administrator

NASA Administrator Bill Nelson gave a virtual presentation at COP26. He emphasized that climate is a key part of the current administration's priorities and stressed its position that climate action requires an "all-hands on deck" approach. He said that "NASA researchers, engineers, innovators, and pioneers are answering [the] call" to take action on climate. He stated that we cannot hope to mitigate the effects of climate change without clearly understanding the science behind it. The agency's Earth-observing satellites provide a unique vantage point for global observations of Earth, which is a source of critical information to advance understanding of our changing planet. He also highlighted NASA's free and open data policy, which the agency strongly encourages all partners to follow.

Nelson reported that the agency is exploring an idea to set up a Mission Control Center for climate change (similar to what it does for every mission and the International Space Station), which will include extensive collaboration with commercial companies and international partners. The actions NASA and its partners take now will help determine the fate of our planet. Acting to address climate change will protect not only the current generation but also those who will follow us in the future. The full presentation is available at *www.youtube.com/watch?v=9xTCBPZi_fw.*

Nelson later stated that "NASA is constantly innovating and bringing our indispensable resources in space to bear to confront the climate crisis. NASA's Earth-observing satellites and instruments provide the U.S. and the world with an unparalleled understanding of our home planet, and we are excited to help deliver urgent change for humanity by taking part in COP26."

NASA Hyperwall Presentations

Throughout the conference, **Gavin Schmidt** [NASA's Goddard Institute for Space Studies (GISS)—*Director* and *Acting NASA Senior Climate Advisor*], **James Green** [NASA Headquarters (HQ)—*Chief Scientist*], and **Susie Perez Quinn** [NASA HQ—*Chief of Staff*] participated in various speaking events and presented material using the Hyperwall—see **Photo 2**.

Photo 2. James Green [NASA Headquarters—*Chief Scientist*] showed COP26 attendees at the U.S. Center the NASA *Earth at Night* book (*go.nasa.gov/3cZKuQK*). **Photo credit:** NASA

Because of COVID-19 concerns, NASA presenters prerecorded their talks, which were then streamed live from the event. These NASA scientists presented 20 talks on the Hyperwall, two per day during the two-week event, showing how NASA's global leadership in climate science and research helps model and predict ocean health, heat waves, wildfires, hurricanes, floods, and droughts. The **Table** on page 12 provides a full list of Hyperwall talks and links to the recordings available on YouTube. **James Green** and **Gavin Schmidt** attended the second week of COP26 in person. They introduced the prerecorded NASA presentations and presenters and answered in-person questions after each talk. Schmidt also gave an in-person talk on November 9, 2021, using visuals from his prerecorded talk of the previous week—see **Photo 3**.

Photo 3. Gavin Schmidt [NASA's Goddard Institute for Space Studies (GISS)—*Director* and *Acting NASA Senior Climate Advisor*] delivered an in-person Hyperwall talk on November 9, 2021. **Photo credit:** NASA

Conclusion

Outreach exhibits such as those implemented at COP26 have traditionally been opportunities for the

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[3] NASA's Science Support Office is the primary point of contact for NASA's Science Mission Directorate and Earth Science Division for science exhibit outreach and product development.

Table. NASA Hyperwall presentations given at the U.S. Center during COP26.

Presentation Title	Presenter	URL
Introduction and Overview of Earth Science	**Karen St. Germain** [NASA Headquarters (HQ)—*Director of the Earth Science Division*]	*youtu.be/MuAvPlBqsYA*
NASA's Role in Tracking and Predicting Climate	**Gavin Schmidt** [NASA Goddard Institute for Space Studies (GISS)—*Director* and *Acting NASA Senior Climate Advisor*]	*youtu.be/CCAcKuJaJOg*
Applications of Satellite Observations to the Global Economy	**Stephanie Schollaert Uz** [NASA's Goddard Space Flight Center (GSFC)—*Applied Sciences Manager*]	*youtu.be/o1Cxdvesk1E*
Satellite View of the Blue Economy	**Laura Lorenzoni** [NASA HQ—*Program Scientist of the Ocean Biology and Biogeochemistry Program*]	*youtu.be/1LLgkRNPyOE*
Revealing Urban Pollution Patterns from a Bird's Eye View	**Laura Judd** [NASA's Langley Research Center (LaRC)—*Associate Program Manager for Health and Air Quality Applications*]	*youtu.be/wuUayB5vdNU*
Carbon in the Earth's Atmosphere	**Lesley Ott** [GSFC—*Climate Scientist*]	*youtu.be/a52zmBtZJm8*
The Global Learning and Observations to Benefit the Environment (GLOBE) Program	**Allison Leidner** [NASA HQ—*Program Manager for Earth Science Education and Communication*]	*youtu.be/2GLyoMKRC-k*
Student Airborne Science Activation for Under-Represented and Under-Served Learners	**Charles Gatebe** [NASA's Ames Research Center—*Chief of Atmospheric Science*]	*youtu.be/ihn2WjYSz4U*
Greenland's Melting in Context	**Lauren Andrews** [GSFC—*Earth Scientist*]	*youtu.be/4ED6N7jySOI*
Ocean Ecology	**Susanne Craig** [GSFC—*Earth Scientist*]	*youtu.be/GyV6B5k_QRA*
Fires in a Warming World	**Doug Morton** [GSFC—*Chief of the Biospheric Sciences Laboratory*]	*youtu.be/7XL21bm33dk*
Climate Variability and Disease Outbreaks	**Assaf Anyamba** [GSFC—*Earth Scientist*]	*youtu.be/KRdWwiF43Qo*
Satellite and Ocean Data Reveal Marked Increase in Earth's Heating Rate	**Norman Loeb** [LaRC—*Atmospheric Scientist*]	*youtu.be/qZgkjgpdzis*
Our Rapidly Changing Arctic	**Patrick Taylor** [LaRC—*Climate Scientist*]	*youtu.be/UWovBdivdcg*
What's Causing Recent Climate Trends?*	**Gavin Schmidt** [GISS—*Director of GISS* and *Acting NASA Senior Climate Advisor*]	*youtu.be/9VVqJGQE5gQ*
How Do We Know for Sure About Atmospheric Aerosols? Ask AERONET**	**Brent Holben** [GSFC—*AERONET Project Scientist*]	*youtu.be/2oxtCOBa3wU*
New Climate for a Better(?) Tomorrow: Earth, Energy, Health, and Water in a Changing Climate	**Nadya Vinogradova Shiffer** [NASA HQ—*Program Scientist* and *Manager of the Physical Oceanography Program*]	*youtu.be/TkdHzepkKzE*
CFC Regulation for Ozone Recovery and a Healthy Planet	**Qing Liang** [GSFC—*Earth Scientist*]	*youtu.be/vU_An4O2OmE*
Connections Between Fire, Weather, and Climate	**Amber Soja** [LaRC—*Earth Scientist*]	*youtu.be/VKAxDc4JBbI*
The Ever-Changing CO_2 Sources and Sinks Seen from Space	**Junjie Liu** [NASA/Jet *Propulsion Laboratory—Earth Scientist*]	*youtu.be/0B-ZsbaiKdg*

*Gavin Schmidt gave his second Hyperwall presentation in person.

**The AErosol RObotic NETwork (AERONET) is a federation of ground-based remote sensing aerosol networks. See *aeronet.gsfc.nasa.gov* for more information.

agency to represent Earth science activities and results, frequently to thousands of people over a very short time—but only in a single location at one particular time. COVID-19 forced NASA—along with the rest of the world—to rethink what these events should look like as we move forward. COP26 was a successful *hybrid* event for NASA that seamlessly integrated in-person activities with virtual presentations. This event is indeed a harbinger of things to come for NASA (e.g., the SSO) and the world.

For example, the 2021 American Geophysical Union's Fall Meeting is planned as a hybrid event, advertised as taking place "*in New Orleans, LA—and online everywhere*" in December. Numerous events planned for 2022 are taking a similar approach.

In keeping with these forward-looking approaches, NASA and the SSO exhibit support team members have quickly adapted to participating in virtual events since March 2020. Among many opportunities brought about by the problems caused by the pandemic, was the chance to help NASA select a virtual exhibit platform,[4] which made its debut in April 2021 when it was used to host the agency's virtual Earth Day activities.[5]

The SSO looks forward to being able to resume its core mission of communicating NASA Science results face to face with individuals and groups of all sizes in the year ahead, as we all strive to facilitate communications between people and organizations, worldwide. The feedback about NASA's efforts—both programmatic and outreach—from attendees at COP26 shows that this is doable. ■

[4] This was a joint effort between NASA (in particular, the SSO) and a private company.

[5] To learn more about NASA's virtual Earth Day activities, read "Connected by Earth: Summary of NASA's 2021 Virtual Earth Day Event" in the May–June 2021 issue of *The Earth Observer* [**Volume 33**, **Issue 3**, pp. 4-11—*go.nasa.gov/3lSmYdi*].

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

ATMS	Advanced Technology Microwave Sounder
CERES	Clouds and the Earth's Radiant Energy System
COP26	Conference of the Parties 26 (to the UNFCCC)
CriS	Cross-track Infrared Sounder
GPS	Global Positioning System
MODIS	Moderate Resolution Imaging Spectroradiometer
NOAA	National Oceanic and Atmospheric Administration
OMPS	Ozone Mapping and Profiler Suite
TEMPEST-D	Temporal Experiment for Storms and Tropical Systems–Demonstration
UNFCCC	United Nations Framework Convention on Climate Change
USGS	U.S. Geological Survey
VIIRS	Visible/Infrared Imager Radiometer Suite

Getting Maximum IMPACT from Earth Science Data

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The IMPACT team supports open science through the thoughtful development of open policies, systematic investment in innovative and collaborative infrastructures, and the promotion of cultural change. This means leveraging the interdisciplinary skills of the team to make the research process, collaborations, and knowledge dissemination more efficient for researchers; just as importantly, it means continuing to work to make science accessible to the broader community, including the general public. As scientific research is shared more openly across various platforms and to different audiences, the impact of scientific contributions to both academia and the broader public is enhanced. This outcome is obtainable, and IMPACT is dedicated to ensuring that all their efforts lead to more open scientific research that will benefit science itself and bring further advances to society as a whole. ■

Partnerships, Co-Production, and Transdisciplinary Science: The 2021 PACE Applications Workshop

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Introduction

The Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission represents one of NASA's next great investments in Earth Science, continuing NASA's legacy of over 40 years of satellite ocean-color measurements. Now scheduled to launch in early 2024, PACE will advance our Earth observing and monitoring capabilities through hyperspectral imaging and multiangle polarimetry of the ocean, atmosphere, and land ecosystems.

The PACE mission hosted its second workshop virtually on September 15-16, 2021. A total of 535 workshop participants (from over 70 countries) included satellite operators, satellite data users, applications developers, applications users, decision makers, and members of novice PACE user communities. This workshop was a follow-on to the highly successful first workshop that took place in 2020 (also held virtually due to COVID-19), which was summarized in *The Earth Observer*.[1] That report contains an introduction to PACE as well as background on PACE Applications and Early Adopters (EA). The PACE Early Adopters Program (*pace.oceansciences.org/app_adopters.htm*) was established in early 2020, and currently consists of 23 teams working on applied research topics spanning the NASA Applied Sciences Program areas (i.e., Disasters, Climate, Ecological Forecasting, Health & Air Quality, Water Resources, and Agriculture).

As with the first workshop, the event brought together an international community of academics; government partners at the federal, state, and local levels; and participants from private organizations, including nonprofit and nongovernmental organizations (NGOs). Participants discussed the mission and how its anticipated data products may be used to support the air quality, water resources, and health sectors through capacity building, training, outreach, and stakeholder engagement. To learn more about NASA's PACE Applications Program, see *pace.oceansciences.org/applications.htm.*

[1] To learn more about the first PACE Applications Workshop, see "Leveraging Science to Advance Society: The 2020 PACE Applications Workshop," in the November–December 2020 issue of *The Earth Observer* [**Volume 32**, **Issue 6**, pp. 18–26—*go.nasa.gov/3pjM31M*].

After setting the context for the second workshop, the remainder of this article provides a summary of the materials presented and discussions that were hosted. Rather than organize the information by session and report chronologically, the content is organized around the four workshop objectives (see next section).

This approach was chosen to highlight how an intentional, creative, and diverse program of activities was used to achieve the workshop's overarching goals. The full workshop agenda, speaker biographies, and recordings of the keynote presentations, panel sessions, breakout sessions, and engagement activities are available at *pace.oceansciences.org/app_workshops_02.htm.*

Motivation and Objectives for the Second Workshop

While the Earth observation research and science community is growing more aware of the hyperspectral and multiangle polarimetric capabilities afforded by PACE, many less-technical stakeholder and user communities do not possess the same level of technological knowledge and readiness to use and apply PACE data. To ensure that the PACE mission and the anticipated data products meet the needs and objectives of applied user and stakeholder communities, NASA's PACE Applications Program aims to build partnerships between data producers and data users. Effective scientific communication, stakeholder engagement, and transdisciplinary research *co-production* or *co-design*—designing and conducting research alongside those who will ultimately use the research output (e.g., a dataset or tool) to ensure greatest viability and applicability for that user—are crucial elements to increase the understanding of PACE capabilities, and in turn broaden the practical applications and societal benefits of future PACE data.

Building on what was accomplished at the first workshop, the objectives of the second workshop were to:

1. Provide an overview of the PACE mission and its planned data products.

2. Understand critical needs and challenges of communities that are interested in PACE data and identify ways to address challenges and barriers to their use.

3. Promote partnerships and community development; encourage engagement and inclusivity within the PACE community, with other Earth missions, with resource managers, and with decision-makers; and identify opportunities for capacity development.

4. Identify advanced and exploratory PACE data products that align with stakeholders needs and identify applications not currently under consideration by the mission.

Workshop Overview and Structure

The 2021 PACE Applications Workshop was designed to ensure participants had the opportunity to connect, contribute, and collaborate productively. Prior to the event, registrants were polled to share their backgrounds, expertise, interests, and demographics, to support the event's hosts facilitating a relevant workshop with engaging conversations.

Each day of the two-day workshop was comprised of one morning session, one afternoon session, and one poster session. In addition, participants were able to choose from five breakout sessions that ran concurrently with each other during the afternoon of Day Two.

The first day's morning session, "NASA Applied Sciences and the PACE mission," was an opening plenary that included five 20-minute presentations intended to introduce these topics to participants at levels geared to facilitating conversation. After the presentations there was an interactive icebreaker activity, organized as an effective way to welcome participants and encourage participation early in the event.

Returning to the technical program, the three subsequent sessions were:

- Engaging with the PACE Air Quality (AQ) Community and Understanding Its Needs;
- Engaging with the PACE Water Quality (WQ) Community and Understanding Its Needs; and
- What Comes Next? Communicating and Expanding PACE Research and Reach for Applications.

The first two technical sessions each consisted of a 30-minute plenary presentation followed by a one-hour moderated panel related to the topics covered in the session. The third session consisted of a series of short presentations followed by the panel discussion.

Each day included a virtual poster session, highlighting the research and applications of PACE. There were specific presentations given each afternoon, with *PACE Early Adopters* featured on Day One and *PACE Science and Application Team (SAT)* featured on Day Two; however, all posters were visible to participants throughout the event. Participants also had the opportunity to join roundtables where they could discuss the project or ask questions of individual EA or SAT members. (This met a need identified in the 2020 workshop in which participants requested additional information on the projects being undertaken by the PACE EAs and SATs.)

During the final session, the participants selected attendance at one of five thematic breakout sessions to serve as a forum for direct interaction with PACE researchers to discuss how anticipated PACE data products might be applied in novel ways.

Objective 1: *Reviewing PACE Applications, PACE Project Science, and PACE Data*

Erin Urquhart [NASA's Goddard Space Flight Center (GSFC)/Science Systems and Applications, Inc. (SSAI)—*PACE Applications Coordinator*] and **Natasha Sadoff** [GSFC/SSAI—*PACE Applications Deputy Coordinator*] served as cohosts for the event. They opened each day of the workshop with a brief overview of NASA's PACE Applications Program and the PACE EA program, both of which serve as mechanisms to build prelaunch partnerships between PACE data producers and data users.

There were then four plenary presentations that together provided an overview of NASA Applied Sciences, the PACE mission, and its anticipated data products.

Emily Sylak-Glassman [NASA Headquarters (HQ)—*Applied Sciences Program Manager*] introduced the NASA Applied Sciences Program portfolio and discussed the end-to-end use of Earth science information to support societal needs and organizational decision making. She explained how innovative and practical applications can help public and private organizations make better-informed decisions. Further, Glassman outlined how improving the capacity of individuals and institutions to access and apply NASA Earth science data and information helps them achieve their unique goals and meet their unique needs.

Andre' Dress [GSFC—*PACE Project Manager*] provided an overview of the three instruments that will fly on the PACE observatory: the Ocean Color Instrument (OCI), a hyperspectral radiometer; and two contributed multiangle polarimeters, the Hyper Angular Research Polarimeter (HARP2), and the Spectropolarimeter for Planetary Exploration (SPEXone). He discussed the conception and history of the PACE mission, its status, and the PACE Project organization.

Jeremy Werdell [GSFC—*PACE Project Scientist*] introduced the general principles of passive remote sensing and presented a snapshot of the groundbreaking

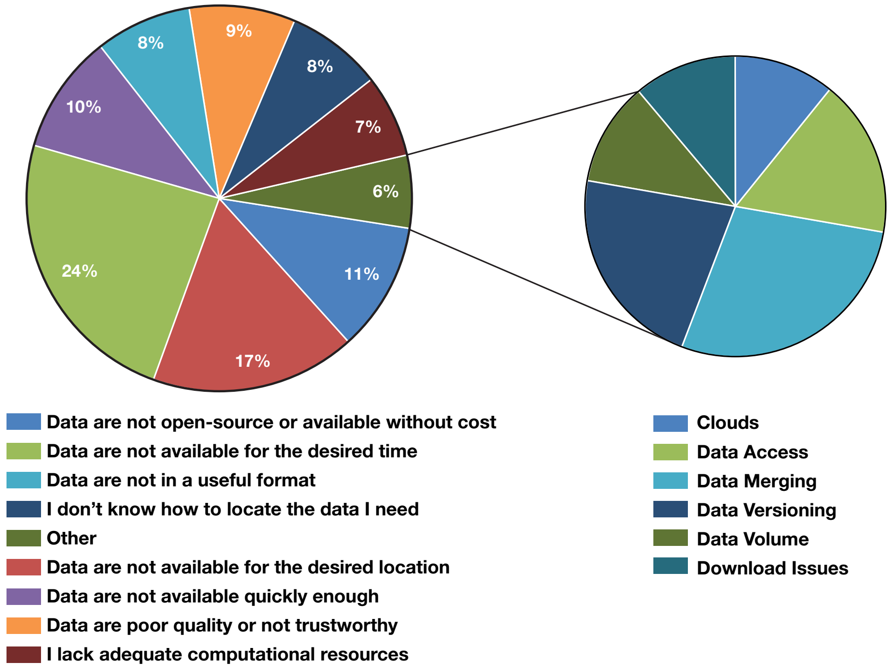

Figure 1. Responses to preworkshop questionnaire, used to assess the challenges or barriers respondents experience in using satellite data in their work (total respondents: 719). **Image credit**: PACE Applications Program

Earth and applied-science capabilities that the PACE instrument suite will enable, including new aquatic bio-optical and biogeochemical retrievals and improved cloud-detection and aerosol retrievals.

Antonio Mannino [GSFC—*PACE Deputy Project Scientist*] provided an overview of PACE OCI, HARP2, and SPEXone data-product-level definitions and formats. He reported that the PACE mission will provide standard and provisional data products once data acquisition begins. Mannino explained how to access, download, display, and process prelaunch and postlaunch PACE data using various software tools. He closed by displaying several images of the recently released simulated OCI data from the Python Top-of-Atmosphere Simulation Tool (pyTOAST) available at *go.nasa.gov/3o4jTbx*.

Objective 2: ***Identifying and Overcoming Challenges and Needs in Using Satellite Data***

The second objective of the workshop was to understand critical needs and challenges of the existing and potential PACE communities that are interested in PACE data, and to establish ways to identify and address those challenges and barriers. This objective aligns closely with one of NASA's PACE Applications Program's goals: *To understand applied user and stakeholder experiences and obstacles in discovering, acquiring, and analyzing remotely sensed Earth data.* By assessing challenges pertaining to data access and use, the PACE mission plans to develop data-discovery and data-delivery tools that maximize the utility and availability of PACE data after launch.

In a preworkshop survey, registrants were polled on the challenges or barriers they've personally faced when using satellite data—see results in **Figure 1**. Most respondents indicated that satellite data are not available for the desired time (e.g., date, historical record, projections, near-term versus real-time data). Other challenges mentioned by workshop registrants were poor data quality, difficulty finding and accessing data, missing data due to the presence of clouds, and unclear satellite data precision and accuracy measures. Other feedback included: an overwhelming number of data-discovery portals to navigate to find data, difficulty merging multiple datasets, frustrations with data versioning and frequent reprocessing, and technical challenges in analyzing satellite data.

Through the dialogues at this workshop, the PACE applied, research, and stakeholder communities were engaged in ongoing efforts to communicate, understand, and assess the challenges that each community faces in working with Earth science satellite data to support their needs. Such discussions are critical to ensuring that the experience and needs of all the relevant communities are heard and addressed—especially the needs of the stakeholders community, who often feel that their needs and challenges are overlooked by scientific researchers and data producers. The PACE mission is determined to integrate this feedback and continue this type of user-experience dialogue to build collaborative partnerships and address these challenges, while ensuring that future PACE data products are accessible, useful, and actionable to support decision makers and address broader societal needs.

Objective 3: ***Pursuing Partnerships, Community Development, and Mission Synergies***

The third workshop objective, which encompassed the majority of the workshop content, was to promote partnerships and community development; encourage engagement and inclusivity within the PACE community, between PACE and other Earth missions, resource managers, and decision makers; and identify opportunities for capacity development. The workshop served as a venue to connect the PACE science and research communities with stakeholder and decision-maker communities. **Emily Sylak-Glassman** reminded the meeting participants that partnerships are a core part of NASA's Applied Science Program's mission. She stressed that Applied Sciences is always looking to develop and expand connections with businesses, foundations, and non-profit organizations, while continuing to build upon their robust partnerships with government agencies.

A common theme that ran throughout all the stakeholder panel discussions, one-on-one meetings, live poster sessions, and roundtable discussion (and also reflected in the results of interactive polling) was the value of stakeholder engagement—early and often—in applied science projects. Sylak–Glassman stressed the importance of integrating user needs through the mission lifecycle, both to prepare data users for post-launch products, and to ensure NASA makes its data products more useful and impactful to these communities. As shown in **Figure 2** below, ranked on a *Likert scale* of 1 (strongly disagree) to 5 (strongly agree), engagement-activity responses from 133 respondents showed that not only have they identified their stakeholders (average rank: 3.5), but that they also understand their stakeholders' needs (3.3), consider their stakeholders' needs when designing projects (3.5), and actively collaborate with stakeholders (3.3).

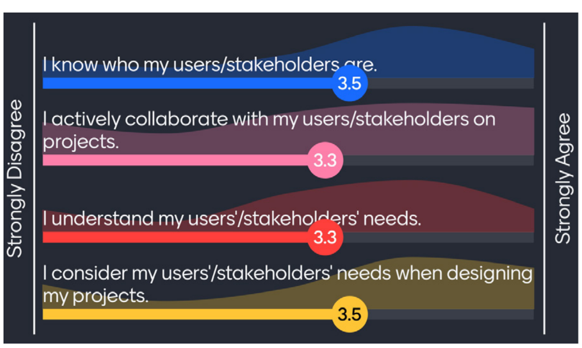

Figure 2. Engagement-activity statements and responses collected during a survey used to assess the level of PACE stakeholder awareness and engagement from September 15, 2021 (total respondents: 133). Numbers are Likert scale values. **Image credit**: PACE Applications Program

Plenary Presentations

Susan Anenberg [George Washington University] gave a plenary presentation sharing insight on using satellite data to assess air pollution and climate change globally. She highlighted several case studies to illustrate how her team partnered directly with stakeholders to bridge the science-to-policy gap, by developing an application to employ reformulated satellite data in a way that is most useful for stakeholders, and how they integrated the satellite-based, co-designed application into the user's environment. She explained that researchers work with *boundary organizations*, i.e., organizations that span the research-to-policy gap and work directly with local decision makers, which allows them to have a direct connection between science and policy.

Maria Tzortziou [City College of New York (CCNY)—*PACE Deputy Program Applications Lead*] showed how transdisciplinary coproduction and multiple-mission synergies can elevate the value, applicability, and actionability of mission data. She emphasized that PACE data will be used to address a number of complex and multifaceted issues that require a deeper level of knowledge than any single discipline can provide. However, such *knowledge integration* can emerge when representatives from a variety of disciplines collaborate. Tzortziou stressed that real-world problems and complex changes need to be understood through *undisciplinary research*, which she defined as research that is problem based, brings everyone to the table (i.e., beyond individual disciplines), and introduces actors outside of science via stakeholders as an integral part of knowledge production.

John Lehrter [University of South Alabama] gave a keynote presentation on how his team used ocean-color satellite data to develop water-quality standards, and how they translated and transitioned those satellite products into a stakeholder's operational environment. He emphasized that his team's biggest challenge was convincing water-quality managers that there is more to a satellite image than a "pretty picture." Lehrter emphasized the importance of educating application managers on how incorporating satellite observations would allow for a significant increase in the amount of data provided, compared to what are available using field observations alone. He said that this was what ultimately convinced his stakeholders and water-quality managers in Florida that their satellite application could work.

Panel Discussion One: PACE Air Quality and Health Community Perspectives Panels

The panelists selected for Panel One were chosen to represent a mock interdisciplinary team of stakeholders in the air-quality community. They range from data producers to application developers to decision makers. Each panelist provided a different perspective on how they approach and manage air quality applications. To ground the discussion in a practical, real-life scenario, the discussion focused on achieving co-benefits of limiting climate change and improving air quality.

Helena Chapman [NASA HQ/Booz Allen Hamilton—*Associate Program Manager for Health & Air Quality*] moderated this panel, which was intended to showcase practical applications of PACE data to support air quality, public health, and decision-making efforts. Panelists discussed their experiences in engaging community end users and offered advice in their answers to this question: *What suggestions do you have for stakeholders and end users who want to use Earth science data or become involved with NASA researchers for air quality and health?*

Juan Jose Castillo [Pan American Health Organization (PAHO)] said that in his experience, "it has been very easy to connect with NASA researchers…", and that, "they are always interested in hearing about how NASA data are being used [in real-world scenarios]."

Marcela Loria [University of Oklahoma] followed up on Castillo's comment about reaching out to NASA researchers by adding that "you [users] just need to be brave enough to ask scientists about what they are doing. They are usually very approachable. Don't be afraid whether you are just starting or if you're further along; just reach out."

Andrew Sayer [GSFC/Universities Space Research Association (USRA)] echoed Loria's sentiment from a NASA researcher's perspective. He reminded the user community that "we know satellite data are difficult to use, with many complexities…we can either help you directly, or point you to a better person, some data-reading tools, or to similar work to what you're doing." Sayer also acknowledged that researchers often use complicated jargon and create diagrams that are unintelligible to stakeholder communities.

Alexei Lyapustin [GSFC] added that "user feedback is extremely useful to our science" and highlighted the crucial role that PACE user input will play in elevating the quality, accuracy, and appropriateness of satellite algorithms and data products.

Abbey Nastan [NASA/Jet Propulsion Laboratory (JPL)] spoke about the benefits of working with other satellite missions, notably, NASA's Tropospheric Emissions Monitoring of Pollution (TEMPO) mission.[2] She explained that mission synergies can "give us a complete picture of the user communities, help keep the users more engaged, and avoid placing additional burdens and demands on end users." Additionally, Nastan discussed mission synergies, particularly between PACE and MAIA.[3] She mentioned that there is an opportunity to explore how the three PACE instruments can provide synergistic data to address outstanding research and application questions not addressable with one instrument alone. Nastan noted the tradeoffs between the instruments, explaining that MAIA will have a higher spatial resolution than PACE's polarimeters, while PACE will offer greater spatial coverage. So, there is an opportunity for these missions to collaborate, although Nastan cautioned that—as of now—each mission is still developing data products in isolation, which makes establishing continuity between missions more difficult. "Every time we retire a mission, the mission users must learn new satellite data products," said Nastan.

Panel Discussion Two: PACE Water Quality Community Perspectives Panel

The panelists for Panel Two were chosen to comprise a mock interdisciplinary team of stakeholders in the water-quality community. They range from data producers to application developers to decision makers. Each panelist provided a different perspective on how they approach and manage water-quality applications. To ground the discussion in a practical, real-life scenario, the discussion focused on *scaling solutions*—or implementing solutions at a variety of spatial and temporal scales—and on addressing issues such as eutrophication and harmful algal blooms.

Stephanie Schollaert Uz [GSFC—*Applied Sciences Manager*] chaired this panel, which showcased practical applications of PACE data to support water-quality assurance, water-resource health and accessibility, and water-quality decision making. Panelists discussed their experiences in engaging community end users, and addressing systemic challenges, and offering advice to those individuals who want to use Earth science data or become involved with NASA researchers for water-quality and water-resource management.

Chris Davis [Maine Aquaculture Innovation Center] began the discussion by stating, "to scale data, we need to work directly with the stakeholders to make [more] user friendly [satellite] tools" and alleviate any additional burden or questions from the users. He mentioned that developing new tools to meet aquaculturists' needs is becoming a significant challenge, particularly as many farmers from diverse backgrounds are joining the industry.

Damian Brady [University of Maine] added perspective as a satellite application developer and researcher, by saying that "in many ways we're still at the very beginning levels of data sharing…we are walking those

[2] TEMPO was the first Earth Venture Instrument selection, also scheduled for 2022 launch; it will make detailed measurements of pollution over North America from geostationary orbit. To learn more about TEMPO, see "NASA Ups the TEMPO on Monitoring Air Pollution," in the March–April 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 2**, pp. 10–15 & 35—*go.nasa.gov/2WGStuX*].

[3] Selected as one of two winning proposals for the third Earth Venture Instrument, MAIA is scheduled for launch in 2022; it will study how different kinds of aerosols impact human health.

people transitioning into aquaculture through the basics of satellite data…" He stressed the importance of connecting environmental information with [environmental] drivers and factors that stakeholders care about, adding that "they care about time-to-market and their return on investment."

Tim Moore [Florida Atlantic University] described his experience working with user communities through a "middleman or boundary organization" such as governmental partners like the National Oceanic and Atmospheric Administration (NOAA). He described the importance of *end-to-end data science*, i.e., the ability to identify and solve problems with the data, to develop usable solutions and value, as part of his PACE research.

Lachlan McKinna [Go2Q Pty Ltd] said that his biggest challenge in working with stakeholders is learning their needs and finding ways to present the science in ways that connect with addressing those needs. He cautioned application and data users against "snake oil salesman" tactics, explaining that while there are many new and exciting data products that satellites can provide, not all of them are particularly helpful or useful for certain applications.

Christine Lee [JPL] echoed earlier concerns about difficulties in developing scaling solutions to enable widespread use for applications, and about the challenge of managing large datasets and data volumes to support the user community. She shared a few lessons learned from NASA's ECOsystem Space-borne Thermal Radiometer Experiment on Space Station (ECOSTRESS) team, noting that the ECOSTRESS team worked to understand the challenges that ECOSTRESS Early Adopters faced when trying to use and analyze data from the mission. This feedback from users helped to guide the Land Processes Distributed Active Archive Center's (the data center for ECOSTRESS) efforts to design methods to more easily subset ECOSTRESS data, thus making it easier for end-users to access and analyze.

Panel Discussion Three: PACE and the NASA Capacity Building Program Panel

The panelists for Panel Three included a representative from each of the activities under NASA's Capacity Building Program (CBP): the Applied Remote Sensing Training Program (ARSET), DEVELOP, and SERVIR.[4] This will lay the foundations for usable, accessible, and actionable data and establish the initial requirements for training, capacity building, outreach, and stakeholder engagement to support applications.

Nancy Searby [NASA HQ—*Program Manager for Capacity Building*] moderated this panel. The panelists discussed how their respective CBP subprograms enable effective partnerships, stakeholder engagement, and capacity development. Below are thoughts they shared when discussing how PACE can be successful in meeting Objective 3.

Amita Mehta [GSFC] explained the importance of meeting different users in different ways, including using "case studies, data access, data applications, and analysis with step-by-step instruction" to reach users of all levels who could apply NASA data. ARSET offers training organized by thematic areas, which correspond to areas where PACE will offer data.

Celeste Gambino [NASA HQ/SSAI] noted that DEVELOP's programming encourages interdisciplinary partner engagement to apply NASA satellite data for decision making through projects. She explained that "wherever project ideas come from, they always center around identifying the priorities and needs of our partner organizations and then determining how NASA data and which Earth observations can be used to inform their environmental decision making."

Eric Anderson [NASA's Marshall Space Flight Center (MSFC)] similarly emphasized that CBP activities are *needs-driven*, prioritizing user consultations and co-development, and implementing an impact statement to better envision and reach success. Incorporating a new dataset is also a risk for decision makers and therefore requires close collaboration with scientists.

In surveys conducted in conjunction with this panel discussion—see **Figure 3** on page 20—32% of the participants indicated that communication (including language barriers and jargon) was their biggest challenge in collaborating with inter/transdisciplinary teams. Other challenges that participants mentioned included establishing mutual priorities (17%), resource constraints (15%), and information sharing—or lack thereof (8%).

Summary Discussion

These three panel discussions underscored the importance of understanding decision-makers' challenges on the job, including dealing with *in situ* data, models, and practical challenges, and considering how partnerships, training, and communication can help enable better uptake and use of Earth science observations. They all recommended that PACE consider several key best practices in preparation for launch: ample

[4] ARSET trains people to use Earth observations to solve our planet's most pressing issues; DEVELOP (not an acronym) is a program in which college students conduct research in Earth Science at NASA Centers; SERVIR is not an acronym, it's the Spanish word for "to serve." The Capacity Building Program works in partnership with leading regional organizations worldwide to help developing countries use information provided by Earth-observing satellites. To learn more about these entities, visit *go.nasa.gov/3djTKim*.

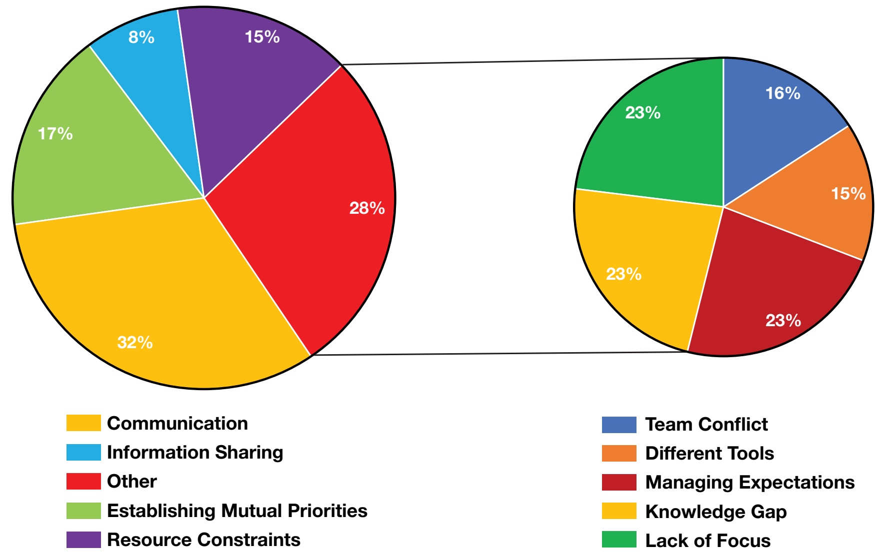

Figure 3. Graphs show challenges in collaborating with inter/transdisciplinary teams from the September 15, 2021, engagement activity responses. **Image credit**: PACE Applications Program

documentation on PACE data products, formats, and their benefits for a diverse set of users; availability of data on Google Earth Engine; and sharing case studies.

Despite the list of challenges that panelists mentioned as barriers to collaboration with inter- and trans-disciplinary teams, workshop attendees agreed that the benefits to applications and the PACE applied and research communities outweigh the hurdles. As noted throughout the workshop, there are measurable benefits from engaging and involving stakeholders in applied research. Stakeholder engagement often leads to working partnerships where feedback can be solicited with new perspectives and insights into another community's needs and experiences. Building lasting partnerships with stakeholders is incredibly important in understanding their needs. Conversations across disciplines or sectors can lead to new ideas, partnerships, collaborations, and projects. In an engagement activity, participants noted that they generally already collaborate with interdisciplinary teams (scoring 4 out of 5 on a Likert scale).

Workshop attendees also shared specific ways to enable collaboration between diverse sectors and different strategies to ensure engagement and inclusivity within the PACE user community. Fostering collaboration and inclusion between diverse audiences and user communities is central to both NASA's PACE Applications and Applied Sciences Programs. The emphasis on practical applications of Earth observation data is becoming more apparent. Encouraging team diversity fosters innovation and collaboration and ensures long-term accessibility, usability, and actionability of PACE data. To achieve this, attendees suggested that scientists or data producers engage in more dialogue and early engagement with data users, that they collaborate with users on the development and design of data products and tools, and they offer to host informal networking opportunities, open meetings, forums, and workshops (e.g., this workshop). Other ideas on strategies to ensure engagement and inclusivity obtained during the activity included establishing working groups, hosting grand data challenges and hackathons, and offering tailored training/webinars on the use of satellite Earth observations—see **Figure 4** on page 21.

Objective 3: *Novel Applications of PACE Data*

One of the desired outcomes of NASA's PACE Applications Program is to discover new applications for PACE data that are not currently being pursued and turn them into new applied science projects. Novel applied research is sought that leverages the PACE mission's capabilities in unique ways for the benefit of society to create additional value and utility for the mission. The workshop was intended to provide an opportunity to begin brainstorming these types of ideas with stakeholders and decision makers, as well as with the PACE applied and research communities. Workshop attendees discussed and shared their enthusiasm for an initial set of ideas that will be assessed for feasibility from PACE data and may potentially be targeted through future PACE EA projects or applied-science capacity-building initiatives. In future events, these preliminary ideas will be used to foster additional conversations in greater depth. Discussing and ideating on novel applications of PACE data will also be a greater focus in the 2022 PACE Applications Workshop, when simulated data will be more widely in use.

Across the various activities during the workshop, several initial research and application ideas were introduced. Related to water resources or marine ecosystems, participants discussed tracking or quantifying marine litter in marine environments using satellite data. They

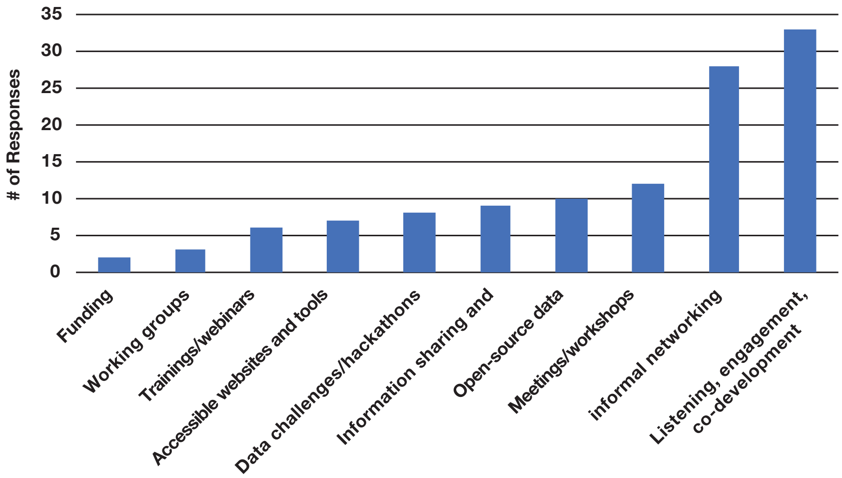

Figure 4. Strategies for ensuring engagement/inclusivity within the PACE user community (from September 16, 2021, engagement activity). **Image credit**: PACE Applications Program

also discussed using observations to identify the full diversity of phytoplankton (i.e., community composition, species composition, Plant Functional Type, or PFT) in new environments. In addition, research on light availability, water quality, shallow-water retrievals, and other metrics in shallow versus deep water environments would benefit existing models. New variables are also needed, such as spectral chromophoric dissolved organic matter (CDOM) absorption coefficient, dissolved organic carbon, benthic characterization, and biogeochemical data products. Other participants suggested using PACE to monitor coral reef ecosystems and to select sites for aquaculture projects.

Regarding atmosphere and air-quality-related research or applications, participants also surfaced several innovative ideas, including monitoring burn scars using surface reflectance (i.e., land cover use/land cover monitoring), monitoring airborne bacteria, and human health monitoring, hot spot identification, and air-quality forecasts based on aerosol levels and types at the neighborhood scale. They also discussed the development of new datasets and an extended record on estimated concentrations of particulate matter with diameter 2.5 µm or less ($PM_{2.5}$) and other measurements of PM (e.g., PM_{10}). Finally, a participant suggested using PACE to further elucidate the connections between climate, aerosols, and aquatic ecosystem change.

There was also a focus on mission synergies and programmatic collaborations that could advance novel applications of PACE data. For example, by using data from both MAIA and PACE, scientists will be able to more effectively quantify aerosol loading and aerosol type, which can inform public health efforts and decision making.

Christine Lee spoke on multiple-mission synergies, noting that seemingly disparate cross-mission data products can be combined to generate a new data product that would not arise from using either datum set alone. She explained that in the case of synergies between NASA Surface Biology & Geology Observable (SBG)[5] and PACE, it is asking how we can leverage the improved temporal resolution of PACE, and use that in combination with improved spatial resolution of SBG to address research and applied science questions.

Maria Tzortziou also highlighted specific synergies between PACE and future geostationary sensors including NASA's TEMPO mission, launching in 2022; Geosynchronous Littoral Imaging and Monitoring Radiometer (GLIMR), planned for launch in 2026;[6] and Geostationary Carbon Cycle Observatory (GeoCARB), launch date to be determined.[7] She also mentioned specific research and applications that will benefit from synergies between PACE and other high-spatial-resolution [20–30 m (~66–98 ft)] hyperspectral missions, e.g., NASA's SBG and the European Space Agency's Copernicus Hyperspectral Imaging Mission for the Environment (CHIME).

Thematic Breakout Sessions

Most relevant to Objective 1 but connecting to all four objectives of the 2021 PACE Applications Workshop, the meeting concluded with five thematic breakout sessions (*Water-Centric, Atmosphere-Centric, Advanced Topics, More Details on the PACE mission,* and *PACE Data Access, Format, and Use*). The breakout sessions served as opportunities to learn about the PACE research community's planned data products and algorithms, as well as future opportunities within the PACE mission. The discussions featured an informal

[5] SBG was one of the designated observables identified in the 2017 National Academies' Earth Science Decadal Survey; it is now one of the missions planned to be part of the Earth System Observatory (*go.nasa.gov/3wmt4pm).* Learn more about SBG at *sbg.jpl.nasa.gov.* The decadal survey, titled "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observations from Space," is available for download *at www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth.*

[6] To learn more about GLIMR, visit *go.nasa.gov/3xBe60i.*

[7] To learn more about GEOCARB, visit *go.nasa.gov/3IamngG.*

presentation, followed by an open discussion centered around product-specific concerns and questions, feedback on coding and data-analysis languages, data-access tools, and brainstorming about potential untapped applications that could create additional utility for PACE data.

Water-Centric: PACE Biogeochemical Stocks, Pigments, and Inherent Optical Properties (IOPs)

Lachlan McKinna [Go2Q Pty Ltd] and **Ivona Cetinić** [GSFC/USRA] moderated discussion in this breakout room. The discussion encompassed technical topics such as how PACE spectral, spatial, and temporal resolutions will support water- and ocean-color applications. Additional topics included phytoplankton community composition, differentiation of phytoplankton species and pigments, and hyperspectral shallow water and coastal retrievals of the photosynthetic pigment, light availability, and chlorophyll-*a,* all useful for management purposes. The moderators also showcased several water-centric PACE EA and SAT synergies to illustrate the mission's capabilities in supporting water-resource management and decision-making activities and to demonstrate how user engagement can help address community needs and goals.

Atmosphere-Centric: PACE Aerosol and Cloud Retrievals

Kirk Knobelspiesse [GSFC], **Andrew Sayer** [GSFC/USRA], and **Meng Gao** [GSFC/SSAI] moderated discussion in this breakout room. The discussion covered the details of the PACE data products and algorithms and the atmospheric capabilities of PACE, namely how the three onboard instruments will enable hyperspectral and multiangular polarimetric (MAP) retrievals of aerosol and cloud properties and when to use each data source for different applications. Technical discussion topics included PACE MAP retrievals for aerosols over land, derivation of cloud properties, simulated and proxy MAP datasets and uncertainties, atmospheric correction, and how PACE data can be used to extend the record of PM globally.

Advanced Topics: PACE Radiometry and Atmospheric Correction

Susanne Craig [GSFC/USRA] and **Bryan Franz** [GSFC] moderated the conversation in this breakout room. The moderators provided a short introduction to several advanced topics, including an overview of ocean color radiometry from PACE, atmospheric correction (AC), the approaches used to compensate and remove the effects of the atmosphere from the surface reflectance signal, and the system's vicarious calibration (SVC) plans to ensure steady and accurate observations of the ocean surface from PACE.

More Details on the PACE Mission

Jeremy Werdell and **Laura Lorenzoni** [NASA HQ] moderated discussion in this breakout room, which was an informal venue for workshop attendees to learn more about the PACE Mission, the Ocean Biology and Biogeochemistry (OBB) program, funding opportunities, and postlaunch PACE plans. Session discussion largely focused on postlaunch PACE validation of threshold and advanced data products, opportunities to co-opt ongoing *in situ* efforts and coordinate with local agencies and end users, and validation methodology including data quality, consistency, and uncertainty. Werdell posed the big-picture question: *What are we missing?*, which led to more conversation around innovative applications of PACE data for terrestrial applications, global modeling, and identifying and mitigating marine plastics and debris.

PACE Data Access, Format, and Use

Antonio Mannino and **Sean Bailey** [GSFC] moderated conversation in this breakout room, providing a venue for open discussion on relevant topics among participants. Audience members posed questions on topics such as scripted access to data, subsetting of hyperspectral files into bands, planned lags in publishing data, availability of simulated data, opportunities for cloud computing, and the possibility of merging files from different instruments. Participants emphasized the need for global coverage, currently provided by heritage products. To the extent possible, plans for data availability will be based on community preferences.

Workshop Recommendations and Feedback

The organizers of the 2021 PACE Applications Workshop conducted a variety of assessments to gauge satisfaction with the event and assess interest in future events. Participants were provided an opportunity to share feedback in a survey which included open-ended questions on sessions and activities of greatest interest, which is summarized in the next subsection. To be responsive to the PACE applied science and user communities, future PACE Applications Program events will continue to address a variety of topics, based on attendees' requests.

Participant Feedback

Workshop participants were inspired by the plenary presentations and live discussions from the *Air Quality & Health Community Perspectives Panel* and the *PACE and the NASA Capacity Building Program Panel*. There was enthusiasm for future PACE Applications Program events to feature plenary presentations and breakout discussions on PACE capabilities and examples for interdisciplinary and transdisciplinary research—particularly to address NASA mission synergies, as well as societal applications of terrestrial science, ocean–atmosphere exchange, and cloud–aerosol impacts on global climate change. Furthermore, workshop participants from both data-user and data-producer communities expressed interest in future tutorial and training events to learn more about PACE data uncertainty, prelaunch proxies, and simulated PACE datasets, and how best to use them in preparatory and applied research projects to build capacity for postlaunch activities. There was a high satisfaction with the robust virtual meeting platform, *Swapcard,* and virtual engagement software, *Mentimeter.com,* with attendees citing the "perfect level of engagement and networking with other participants while still being able to focus on the workshop programming and content."

The Way Forward

In the coming months, the PACE Applications Program team will use the feedback obtained during and after the workshop to develop and design future events to build on the success of this workshop. Ultimately, these activities will support the integration and adoption of anticipated PACE data into practical applications that benefit society and build active partnerships between data producers and the PACE applications and user communities. The NASA PACE Applications Program team will continue to engage and interact with applied research, data-user, and stakeholder communities, soliciting their feedback to inform future mission and application activities to fulfill practical societal needs, enable efficient data-driven decision-making processes, and foster collaborative inter- and transdisciplinary partnerships.

Conclusion

The 2021 NASA PACE Applications Workshop was the second in a series of anticipated annual PACE Applications events focused on building the PACE applications end-user community and providing input to the science team on future uses for PACE data. The 2021 workshop set timely objectives, all of which were meaningfully addressed through keynote presentations, moderated panel discussions, poster sessions, and engagement activities throughout the two-day event. As a virtual forum, the workshop achieved an incredible level of global interest and multidisciplinary turnout, with a high level of engagement and interaction among the hosts, presenters, and participants. The workshop enabled a transdisciplinary dialogue focused on the PACE mission and how its anticipated data products will support societal needs across the air quality and water quality communities and began the critical discussion of broader reach through capacity building, training, and outreach.

The workshop was a resounding success for the PACE mission and its continued support for broader NASA applied-science initiatives. This momentum will be carried into programming in 2022 and beyond, including future focus sessions, annual workshops, and other community engagement activities. As always, news of future meetings and events will be posted to the PACE Applications Program website. ■

Summary of the Seventh DSCOVR EPIC and NISTAR Science Team Meeting

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Introduction

The seventh Deep Space Climate Observatory (DSCOVR) EPIC and NISTAR[1] Science Team Meeting (STM) was held virtually September 28-30, 2021. Over 60 people attended, most of whom were from NASA's Goddard Space Flight Center (GSFC), with several participating from other NASA centers, U.S. universities, and U.S. Department of Energy laboratories. There were also several participants from Finland and Estonia.

A full overview of DSCOVR was given in the summary of the 2018 DSCOVR STM and will not be repeated here.[2] This article presents the highlights of the 2021 meeting; the meeting agenda and full presentations can be downloaded from *go.nasa.gov/3pdoKXb.*

Opening Presentations

The opening session consisted of a series of presentations from DSCOVR mission leaders and representatives from GSFC, the National Oceanic and Atmospheric Administration (NOAA), and NASA Headquarters (HQ), who gave updates on the mission and the two Earth-viewing science instruments onboard.[3]

Alexander Marshak [GSFC—*DSCOVR Deputy Project Scientist*] opened the meeting. He discussed the agenda for the meeting (which was being held virtually for a second year due to the ongoing COVID-19 pandemic) and mentioned that both Earth science instruments on DSCOVR are functioning normally, that there are two new EPIC products [Ocean Photosynthetically Active Radiation (PAR) and Sun Glint], and that there are now more than 70 papers related to DSCOVR listed on the EPIC site (*epic.gsfc.nasa.gov*). He also mentioned that the Special Issue of *Frontiers in Remote Sensing* titled "DSCOVR EPIC/NISTAR: 5 years of Observing Earth from the first Lagrangian Point," has 19 papers submitted (11 papers accepted and published).[4]

Jack Kaye [NASA Headquarters (HQ)—*Associate Director for Research, Earth Science Division (ESD)*] welcomed the members of the DSCOVR Science Team and all friends of EPIC and NISTAR observations. He gave a brief overview of the NASA Earth science budget and current and future Earth science missions.

Adam Szabo [GSFC—*DSCOVR Project Scientist*] welcomed the STM participants and briefly reported that the spacecraft was still in good health and the EPIC and NISTAR instruments continue to return their full science observations. For more, see Amanda Raab's report in the next section.

Steve Platnick [GSFC—*Deputy Director for Atmospheres in the GSFC Earth Sciences Division*] welcomed meeting participants to the virtual meeting on behalf of Goddard Earth sciences. He thanked NASA HQ for its continued strong interest in the mission. Platnick also expressed his appreciation for the mission team members who have worked hard to maintain operation of the DSCOVR satellite and instruments during this challenging time.

Richard Eckman [NASA HQ—*DSCOVR EPIC/NISTAR Program Scientist*] echoed **Jack Kaye's** sentiments, again welcoming individuals and teams from DSCOVR, EPIC, and NISTAR to the meeting. He looked forward to learning about recent accomplishments by Science Team members. Eckman also discussed the DSCOVR Science Team recompete, reporting that proposals had been received in response to the Research Opportunities in Space and Earth Sciences (ROSES) call for the DSCOVR Science Team in September, and that the evaluation process was underway.

Updates on DSCOVR Operations

The DSCOVR mission components continue to function nominally, with progress being reported on several fronts, including data acquisition, processing, archiving,

[1] The two Earth-viewing instruments onboard DSCOVR are NASA's Earth Polychromatic Imaging Camera (EPIC) and the National Institute of Standards and Technology (NIST)'s Advanced Radiometer (NISTAR).

[2] See "Summary of DSCOVR EPIC and NISTAR Science Team Meeting" in the November-December 2018 issue of *The Earth Observer* [**Volume 30, Issue 6,** pp. 16-22— *go.nasa.gov/37c0M5s*].

[3] From its vantage point one million miles from Earth at the first Lagrangian point (L-1), the full DSCOVR mission observes both the Earth and the Sun. A third instrument, the plasma-magnetometer (PlasMag), measures space weather conditions, and is not reported on here.

[4] UPDATE: The numbers cited here were as of the meeting date. As the November–December 2021 issue of *The Earth Observer* went to press the numbers were up to 23 papers submitted and 17 accepted.

and release of new versions of several data products. The number of users is increasing, with a new Science Outreach Team having been put in place to aid users in several aspects of data discovery, access, and user friendliness.

Amanda Raab [NOAA)] presented an update on the status of the observatory, which is working nominally. DSCOVR is anticipated to continue to operate through the next five years barring any unexpected failures. DSCOVR mission operations engineers are working to execute the last maneuver in its series of Solar Exclusion Zone maneuvers (targeting October 2021).[5] These maneuvers keep the spacecraft from drifting in front of the Sun, which typically causes communication interference.

Carl Hostetter [GSFC] described the DSCOVR Science Operations Center (DSOC)'s EPIC and NISTAR data flow from the spacecraft, through the receiving ground station(s) to the Science Planetary Operations and Control Center (SPOCC), and the subsequent processing of these data to Level-1A (L1A) and L1B science data products, including their archiving and distribution to the public.

NISTAR Status and Observations

NISTAR remains fully functional and continues its uninterrupted record. The presentations here include more details on specific topics related to NISTAR, or on efforts to combine information from both EPIC and NISTAR.

Data Processing

Allan Smith [L-1 Standards and Technology, Inc.] reported on two processing updates for the NISTAR shortwave channel: an improved, time-dependent offset that will replace the interpolated monthly measurements currently being used, and a correction for the moonlight that frequently and significantly contaminates Earth observations. The lunar-light correction will allow the use of most data that are currently flagged as unusable when the Moon is within the NISTAR field of regard. Ongoing maintenance of processing software has improved processing speed, corrected a small error in the NISTAR pointing calculation,[6] and ensured compatibility with future publishing requirements—all necessary activities, but none of which impacts NISTAR data users.

Characterization

Clark Weaver [University of Maryland, Earth System Science Interdisciplinary Center, College Park] described research to measure the shortwave reflected energy for each pixel of an EPIC image using several visible-wavelength (VIS) channels. To fully characterize the broadband shortwave spectrum, the data were augmented with appropriate spectra from the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS). Preliminary results showed that the EPIC–AVIRIS composite for an EPIC image is within 5 W/m^2 of the shortwave NISTAR Band-B observations, which is reasonably good agreement.

Andrew Lacis [NASA's Goddard Institute for Space Studies (GISS)] reported that a unique climate diagnostic has been developed to detect and differentiate the interannual El Niño and Southern Oscillation variability utilizing the EPIC-generated spatiotemporal variability of the Earth's planetary albedo measured over the sunlit hemisphere from a Sun-Earth Lagrangian, or "L-1," point.[7] He also explained that although the conversion from NISTAR near-backscattered shortwave (SW) and emitted longwave (LW) radiance to full-spectrum SW and LW radiative flux is still undergoing some modeling and calibration refinements, the NISTAR Band-C/Band-B near-IR-to-total-SW spectral ratio sidesteps these issues of calibration and radiance-to-flux conversion to provide a unique constraint—one that is not available from other satellite data—on the spectral distribution of absorbed solar radiation.

Daniel Feldman [Lawrence Berkeley National Laboratory] reported that the Earth's reflected shortwave radiation (RSR) had exhibited remarkable long-term stability in spite of its temporal variability ranging from subdaily to interannual timescales. The subdaily observations of RSR from NISTAR and EPIC have been used to validate subdaily CERES[8] Synoptic top-of-atmosphere (TOA) and Surface Fluxes and Clouds (SYN) products, revealing that the diurnal filling in of the CERES SYN process chain is robust. Feldman explained that a time-series analysis revealed that reflected shortwave radiation (RSR) can be modeled as a red-noise process on superdiurnal-to-interannual timescales. The serial correlation of a red-noise process at these timescales arises because the Earth's albedo exhibits a mode of variability on diurnal time-scales due to the zonal contrast in surface albedo

[5] UPDATE: This maneuver took place as planned.

[6] When the DSCOVR spacecraft slews away from the Earth, the exact point at which data are flagged as *invalid* (meaning not Earth viewing) will change slightly. Consequently, a very small number of data points that were previously flagged as valid, may have been invalid—meaning some of the Earth disk is outside the field of view. However, because the optical response rolls off gradually, even then, the radiometric errors are negligible.

[7] Objects at Lagrangian points in space are at gravitational equipotential with several masses and so remain "fixed" in orbit relative to those masses. Note that in this context, "L-1" does not refer to Level-1 (L1) data products.

[8] CERES stands for Clouds and the Earth's Radiant Energy System. There are currently six CERES instruments in orbit: two on Terra, two on Aqua, one on Suomi NPP, and one on NOAA–20. There was formerly a CERES instrument on the Tropical Rainfall Measuring Mission (TRMM), which ended in 2015.

and clouds as the Earth rotates, but at longer timescales, that mode of variability also is affected by the Earth's tilt and clouds.

Possible Future Earth Observations from Lagrange Points

Francisco Valero [University of California San Diego] demonstrated the scientific value of remote sensing the Earth from a million miles away at the L-1 point. He summarized a proposed augmented Integrated Earth Observation System (IEOS) that would advance the Earth and climate sciences from observations taken at the Lagrange points (there are five such points in the Earth–Sun system) and tap into the potential for future development of applications of these observations. It includes more-capable DSCOVR-like satellites at L-1 (daylight observations) and L-2 (nighttime observations) points possibly with the addition of Artificial Lagrange Orbits (ALOs) platforms. Since all low-orbit and geostationary-orbit satellites are within the full-disc, sunlit view of DSCOVR, data from those platforms can be integrated with DSCOVR observations throughout the daytime to implement this proposed IEOS system, with Lagrange-point satellites serving as the "anchor" and the Moon as a stable reference for instrument calibration.

EPIC: From Data to Science

EPIC now produces a full suite of 11 science products and makes them available to the scientific community via the Atmospheric Science Data Center (ASDC; *asdc.larc.nasa.gov/*). As a result of a release of Version 3 (V3) of the L1 data—with much better geolocation—scientific results from EPIC data have been substantially improved. Calibration activities, which covered flat-field calibration, led to ozone retrieval improvements, improved channel calibration coefficients, and the use of lunar observations for calibration trending. The presenters in this section gave meeting participants the latest progress reports on the EPIC journey from data to science, touching on issues related to data processing and calibration.

Data Processing

Alexander Cede and **Gavin McCauley** [SciGlob] reported that no abnormalities in EPIC L1A[9] data have been detected in the past year and that the detector continues to function normally with no pixels turning hot. The dark map used in the current EPIC operational processor still accurately describes the true dark count. Cede noted that the next version of the processing algorithm—which will be used once the processor is upgraded—will include an improved flat field, implemented by including a vignetting effect based on results of the lunar calibrations, and a correction to eliminate an erroneous stray-light correction in the vicinity of enhanced pixels.

Marshall Sutton [GSFC] discussed generating and archiving EPIC L2 science products for all EPIC science teams. A suite of eleven L2 data products are generated from L1 EPIC data. The high-performance computing capabilities offered through the NASA Center for Climate Simulation's (NCCS) Discover cluster were used to store algorithms, download ancillary data, process the data, and upload to the ASDC data repository.

Karin Blank [GSFC] presented the current status of the EPIC geolocation and reported on some changes that were made to improve accuracy. She also discussed using astronaut photography for color calibration.

Tim Larson [LaRC] presented DSCOVR L1 and L2 metrics up to August 28, 2021, showing new visualizations of each data version. Larson also provided the number of distinct users and number of orders for EPIC and NISTAR L1A and L1B products.

Calibration

Igor Geogdzhayev [Columbia University] discussed EPIC VIS and near-infrared channels calibration using matching scenes from multiple low-Earth-orbit (LEO) radiometers (MISR, MODIS, VIIRS).[10] He mentioned that the analysis of trends for the entire EPIC data set revealed that the instrument has been remarkably stable. No statistically significant changes in calibration were found after the instrument's exit in March 2020 from safe hold from June 27, 2019, to February 11, 2020, caused by problems with its positioning systems. Data analysis and radiative transfer modeling showed that the effects of EPIC–LEO radiometer geometry differences are small for scattering angles smaller than 177°.

David Doelling [NASA's Langley Research Center (LaRC)] reported that EPIC is extremely stable, as validated by intercomparisons with MODIS (on Aqua) and VIIRS (on Suomi NPP). The EPIC V3 L1B navigation is greatly improved over V2, allowing for EPIC Earth invariant target calibration over the Libya-4 Pseudo-invariant Calibration Site (PICS),[11] and over deep convective clouds, confirming its stability. Since EPIC scans images throughout all local hours of the

[9] Note that in the context of the following material, the L1-type designation refers to standard data processing levels, not Lagrangian points.

[10] MISR stands for Multi-angle Imaging SpectroRadiometer, which flies on NASA's Terra platform; MODIS stands for Moderate Resolution Imaging Spectroradiometer, which flies on NASA's Terra and Aqua platforms; VIIRS stands for Visible Infrared Imaging Radiometer Suite, which flies on the Suomi National Polar-orbiting Partnership (Suomi NPP) satellite and on NOAA–20.

[11] Libya-4 is located in the Great Sand Sea of the Sahara Desert. The area is made up of sand dunes with no vegetation, making it an ideal site for calibration of optical sensors on Earth observing satellites. Learn more at *calval.cr.usgs.gov/apps/libya-4*.

day, it can be used as a transfer radiometer to validate radiometric scaling factors between sensor pairs, to perform sensor calibration drift corrections, and to derive stable narrowband to broadband fluxes, all of which are helpful to the CERES project. The EPIC V3 L1B absolute calibration reference is within the uncertainty of both the VIIRS and MODIS sensors described earlier—which is remarkable given that it has no onboard calibration.

Updates on EPIC Level-2 Data Products

The presenters during this session gave updates on the status of and/or science results obtained using the various EPIC L2 data products. These products have been released to the public through the ASDC at LaRC. For more details, refer to the original presentations via the URL provided in the Introduction.

Total Column Ozone

Natalya Kramarova [GSFC] reported on V3 of EPIC ozone retrieval algorithm, which features improved geolocation, calibration, and algorithmic updates. The accuracy of total ozone measurements from EPIC have been evaluated using correlative satellite and ground-based total ozone measurements at time scales from daily averages to monthly means. The comparisons showed good agreement with increasing differences at high latitudes. Evaluation of the EPIC ozone time series at different ground-based stations with the correlative ground-based and satellite instruments demonstrated good consistency in capturing ozone variations at daily, weekly, and monthly scales with a consistently high correlation.

Tropospheric Ozone

Jerald Ziemke [Goddard Earth Sciences Technology and Research (GESTAR)] described tropospheric ozone retrievals from EPIC, a new data product that is comprised of gridded synoptic maps of tropospheric column ozone (TCO) measured over the sunlit portion of the Earth disk every one-to-two hours. EPIC's unique high-temporal-resolution TCO measurements are ideal for tracking pollution events such as uncontrolled wildfires over California and Brazil. EPIC's long record reveals low (5–10%) anomalous reductions in TCO throughout the Northern Hemisphere in spring–summer 2020 during COVID-19—when there was large reduction of pollution, including ozone precursors in the troposphere generally—see **Figure 1**.

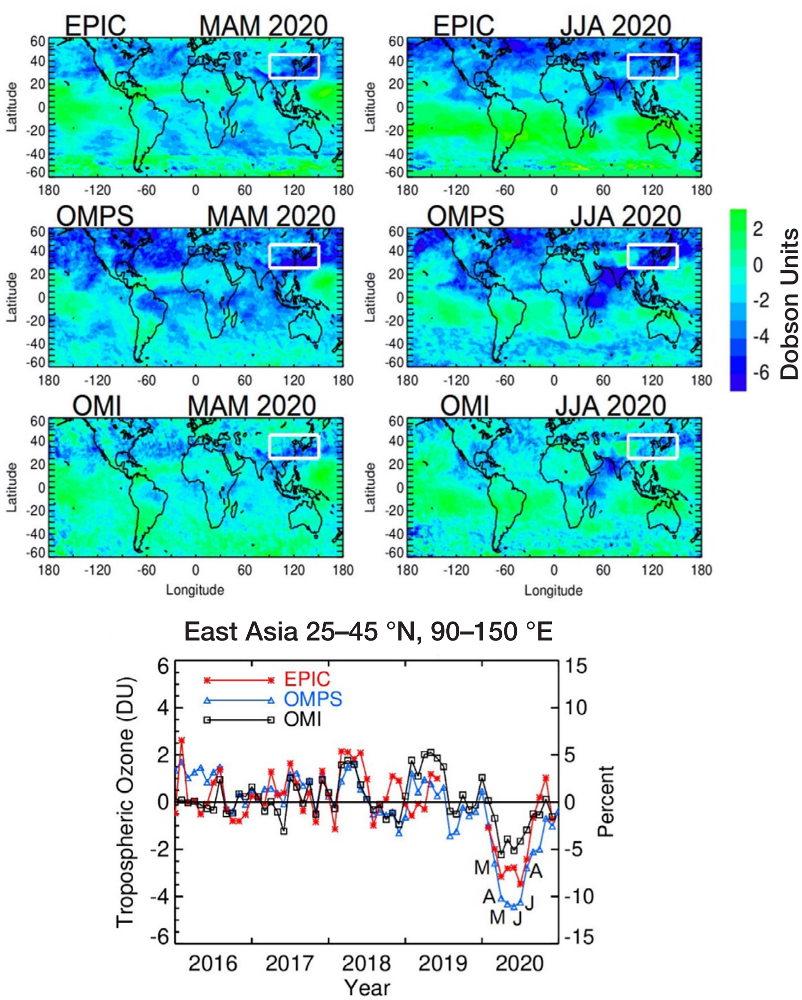


Figure 1. EPIC retrievals of tropospheric column ozone (TCO) compare favorably with those obtained by the Ozone Monitoring Instrument (OMI) on NASA's Aura satellite and the Ozone Mapping Profiler Suite (OMPS) on the Suomi National Polar-orbiting Platform (Suomi NPP) and NOAA-20 satellite. The maps show seasonal *anomalies* (departures from four-year average fields for 2016–2019) for EPIC [*top row*], OMPS [*middle row*], and OMI [*bottom row*] tropospheric ozone measurements, for March, April, May (MAM) 2020 [*left column*], and June, July, August (JJA) 2020 [*right column*]. EPIC observations (as well as those from OMI and Aura) reveal 5–10% reductions in TCO throughout the Northern Hemisphere in spring (MAM) and summer (JJA) 2020 during the COVID-19 shutdowns—when there was large reduction of pollution, including ozone precursors in the troposphere generally. The graph shows the comparison of the three instruments for East Asia [the area in the box on each map]. Notice the pronounced drop in TCO in early 2020, which begins rise again later in the year as "normal" activities resumed in this region. **Image credit**: Jerald Ziemke

Volcanic Sulfur Dioxide

Simon Carn [University of Michigan] discussed new volcanic eruptions that have been detected using the EPIC Volcanic Sulfur Dioxide (SO_2) product in 2020–2021. In particular, he noted that the explosive eruption of La Soufrière (St. Vincent) in April 2021 was the largest tropical eruption that has occurred during the DSCOVR mission. Carn described how volcanic ash impacted SO_2 retrievals in the 2021 eruption of La Soufrière volcano. The next iteration of the EPIC volcanic SO_2 product will introduce an aerosol correction to help mitigate the impact of volcanic ash on future retrievals.

Algorithm Improvements for Ozone and Sulfur Products

Kai Yang [University of Maryland, College Park] presented information on algorithm advances that improve EPIC ozone (O_3) and volcanic SO_2 products. Validation with coincident ground-based O_3 measurements from the Brewer spectrophotometer network showed that the accuracy of the EPIC total O_3 was greater than or equal to those from other satellite instruments—with superior spectral coverage and higher signal-to-noise ratios. Yang showed several examples from several recent volcanic eruptions, including the successful characterization of the 2021 La Soufrière eruption, made possible because of simultaneous retrieval of volcanic SO_2 and ash.

Ultraviolet and Visible Aerosol Optical Depth and Single Scattering Albedo

Omar Torres [GSFC] provided an update on ongoing routine validation activities for EPIC ultraviolet (UV) aerosol optical depth (AOD) single-scattering albedo products. He discussed the transition from the use of aerosol layer height climatology from the Cloud–Aerosol Lidar with Orthogonal Polarization (CALIOP)[12] to operational aerosol height retrievals using oxygen B-band observations. Torres also explained the advantages of using EPIC near-UV radiances for wildfire research. He showed that such observations are particularly suited for the detection and characterization of stratospheric carbonaceous aerosols.

Alexei Lyapustin [GSFC] presented V2 of the Multi-Angle Implementation of Atmosphere Correction (MAIAC) EPIC algorithm, which features significantly improved aerosol retrievals over land and anisotropic atmospheric correction, replacing the Lambertian approximation used in V1. He explained that V2 also includes simultaneous retrieval of aerosol optical depth retrieval of AOD, and spectral aerosol absorption based on EPIC UV–VIS observations.

Cloud Products

Yuekui Yang [GSFC] reported on the status of the EPIC L2 cloud products, which have been upgraded to V3. He said that significant improvements in this new version of the algorithm include cloud mask over snow and ice, and over ocean sun glint. Yang explained that EPIC V3 cloud products have been compared with cloud products from the Geostationary Operational Environmental Satellite–16 (GOES-16) and with the LaRC Geostationary Earth Orbit (GEO)/LEO composites. He showed some results to demonstrate that the EPIC cloud products perform well and match theoretical expectations.

Cloud Mask Algorithm Update

Yaping Zhou [GSFC] described recent improvement in the EPIC cloud mask algorithm over the ocean, especially over regions with bright surface reflection, e.g., sun glint. She reported that algorithm performance is significantly improved over regions with sun glint and high zenith angles when compared with retrievals from the GEO and LEO observations. The new ocean cloud mask enables more-realistic analyses of cloud daily variability by removing the artificial peak at local noon in the glint center latitudes and reducing biases in the cloud fraction in the early morning and late afternoon over ocean.

Vegetation

Yuri Knyazikhin [Boston University] discussed V2.1 of the Vegetation Earth System Data Record (VESDR). He explained that five parameters have been developed and added to the VESDR parameter suite: Earth Reflector Type Index (ERTI) and Canopy Coefficients at several wavelengths. Knyazikhin also reported that the V2.1 operational algorithm has been finalized and its performance evaluated on a limited set of data over South America. Results suggest that spatial coverage increased by 5–6%; the difference between MODIS and EPIC Leaf Area Index (LAI) was reduced to 0.24 LAI units; LAI retrievals are better localized; and "blockiness" in images found in previous versions is gone.

Sun Glint

Tamás Várnai [University of Maryland, Baltimore County (UMBC), Joint Center for Earth Systems Technology (JCET)] discussed the recently released EPIC L2 glint product—the first satellite data product dedicated to sun glint. He explained that this product identifies glints that often appear in EPIC images due to the specular reflection of sunlight either from horizontally oriented ice crystals occurring in clouds

[12] CALIOP flies on the Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) mission *calipso.cnes.fr/en/CALIPSO/lidar.htm*.

or from smooth water surfaces such as calm oceans—see **Figure 2** for examples of both. Várnai described the glint detection algorithm, including examples and statistics of glint detection results. Such results are expected to yield new insights on glint-causing objects—e.g., about the microphysical and radiative properties of ice clouds.

Ocean PAR

Robert Frouin [University of California, San Diego] described an algorithm that estimates daily PAR at the ice-free ocean surface from EPIC/DSCOVR data. He explained that the algorithm uses a budget approach, in which the solar irradiance reaching the surface is obtained by subtracting from the irradiance arriving at the top of the atmosphere (known) the irradiance reflected to space (estimated from the EPIC Level 1b data), taking into account atmospheric transmittance and surface albedo (modeled). Frouin reviewed the uncertainties that are associated with each PAR estimate. A preliminary evaluation shows good agreement with PAR estimates from other satellite sensors and *in situ* measurements at ocean moorings. EPIC PAR products are now generated routinely at NCCS and distributed by ASDC. Additional EPIC surface radiation products are being developed to address science questions pertaining to biogeochemical cycling of carbon, nutrients, and oxygen, as well as mixed-layer dynamics and circulation—in particular, spectral and integrated scalar irradiance just below the surface over the PAR and UV-A ranges.

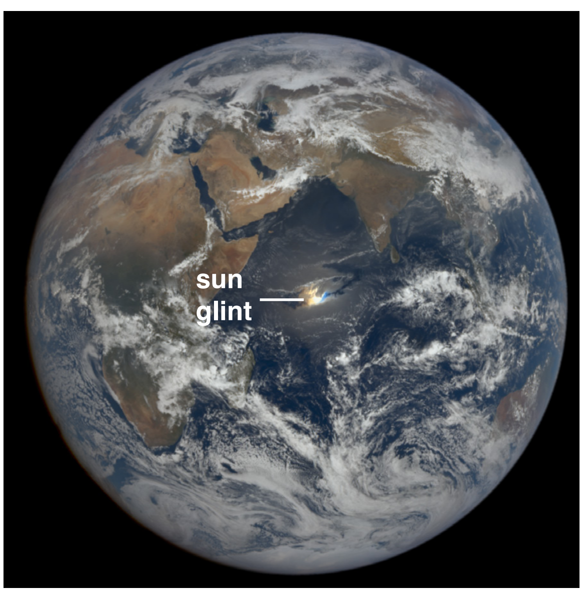
DSCOVR Science from EPIC and NISTAR

As is evident from the summaries that appear in this section, EPIC and NISTAR have been used for a wide range of Earth science investigations. More information on many of the topics discussed here can be found in the full presentations posted at the website provided in the Introduction.

Intersensor Comparisons and Effect of Scattering Angle

Alexander Marshak discussed the effect of scattering angle on EPIC and NISTAR measurements. He reported that all EPIC observations, except over ocean under clear sky, show a strong increase of reflectance towards backscattering direction. The increase is well confirmed with cloud and vegetation models. NISTAR observations also demonstrate an increase with scattering angle for all bands, but the strongest one is for oxygen B-band radiance (0.2–4 μm). Any angular distribution model with a bin size bigger than 1–3° near backscattering may lead to substantial errors.

Wenying Su [LaRC] reported that EPIC offers a testbed for the CERES angular distribution models (ADMs). As the EPIC relative azimuth angles change from 168° to 178°, the global daytime mean SW radiances can increase by as much as 10%—even though no notable cloud changes are observed. The global daytime mean SW fluxes derived after considering the radiance anisotropies at relative azimuth angles of 168° and 178° show much smaller differences (<1%), indicating increases in EPIC SW radiances are due mostly



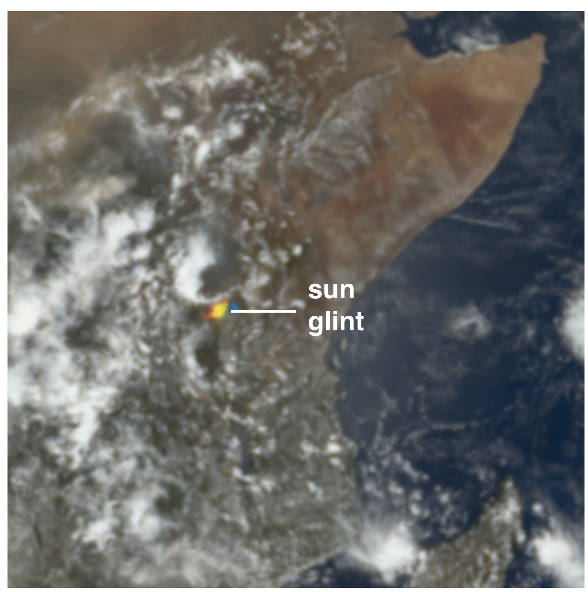


Figure 2. EPIC can detect sun glint and [by comparing measurements obtained from two oxygen absorbing bands centered at 688 nm (B-band) and 764 nm (A-band) to estimate where it originates] researchers can tell if the glint is caused by light reflecting off smooth water surfaces from ice crystals or off the surface of ice crystals in high-altitude clouds (e.g., cirrus). Shown here are two sun glint images: one from the surface of the Indian Ocean [*left, go.nasa.gov/32Bl2Po, click on image #5*] on March 23, 2016 at 7:39 UTC and the other from ice crystals in high clouds over Central Africa [*right, go.nasa.gov/3llFWJ5, click on image #6*] on March 17, 2016. **Image credit**: EPIC website

to changes in viewing geometries. Furthermore, annual global daytime mean SW fluxes from EPIC agree with the CERES equivalents to within 0.5 W/m^2 with root-mean-square (RMS) errors less than 3.0 W/m^2. Consistency between SW fluxes from EPIC and CERES inverted from very different viewing geometries indicates that the CERES ADMs accurately quantify the radiance anisotropy and can be used for flux inversion from different viewing perspectives.

Young-Kwon Lim [GSFC] examined TOA reflected shortwave solar radiation from CERES observations, as well as from the NASA's Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) and the European Centre for Medium-Range Weather Forecast's Reanalysis, Version 5 (ERA5), to better understand their differences in spatial and temporal variations with respect to the observations from EPIC. The seasonally averaged shortwave radiances from CERES match well with the broadband EPIC radiances with 2–3% mean absolute error over the tropical-midlatitudes. Relatively poor performance from reanalyses over the tropical western Pacific and over low-cloud regions off the west coast of the U.S. causes the largest shortwave radiance errors during the boreal summer, while the error is smallest during the boreal winter.

Aerosols

Sujung Go [GSFC] presented a retrieval algorithm to determine aerosol chemical species content in the atmosphere from EPIC observations. The results display variations—both spatial and temporal—within the published ranges of hematite and goethite over the main dust source regions. Moreover, the EPIC MAIAC confirmed that freshly emitted smoke aerosols from western North American and Siberian wildfires exhibited high fractions of black and brown carbon near sources and the absorption decreased with time as the absorbing species were transported away from the source regions. The algorithm can be applied to other single-view on-orbit instruments with UV–VIS channels. This novel information—presently unavailable from other operational satellites—provides an important input for climate modeling and air quality studies.

Zhendong Lu [University of Iowa] demonstrated the applications of EPIC aerosol optical centroid height retrieval in air quality and climate studies. The monthly and hourly climatologies of Saharan dust plume height are characterized through the aerosol optical central height (AOCH) retrieval using four years of EPIC measurements (June 2015–June 2019). There is good agreement between CALIOP L3 product and CATS data,[13] respectively, but EPIC data have larger spatial and temporal coverage than CALIOP and CATS. However, MERRA-2 data can capture little diurnal variation of Saharan dust plume height, which demonstrates the value of EPIC AOCH data in constraining the aerosol layer height in climate models. For air quality studies, the study retrieved the hourly smoke layer height for the 2020 fire season in the western U.S. and explored the quantitative relationship between smoke vertical velocity and hourly variation of surface particulate matter with diameter less than or equal to 2.5 µm ($PM_{2.5}$) through a box model. The observational data can be fitted very well with this box model, which highlights the value of EPIC AOCH data in improving the hourly $PM_{2.5}$ estimates.

Clouds

Anthony Davis [NASA/Jet Propulsion Laboratory] discussed a history of cloud height retrievals using O_2 absorbing bands, followed by a physics-based approach for retrievals including an invariance property of mean in-cloud path length. He proposed a new algorithm that uses both the mean and variance of path length. The algorithm pairs statistical and physical approaches.

Alfonso Delgado Bonal [Universities Space Research Association (USRA)] said that global diurnal variability of cloud properties remains largely unexplored, mainly due to satellite orbital constraints. He described a methodology to study cloud fraction diurnal changes with EPIC data along with coincident GOES-R cloud-height retrievals. In both cases, the results show that cloud height exhibits a minimum around midday for low clouds with two-fold amplitude changes, depending on the season. In contrast, high clouds exhibit a steady increase from morning to evening. The amplitude of the cycles is smaller over ocean than over land, and for low clouds there is a positive correlation between cloud fraction and height over ocean which turns negative over land, while for high clouds the correlation is largely positive.

Surface Phenomena

Ranga Myneni [Boston University] presented a new approach for generating hot-spot signatures of equatorial forests from synergistic analyses of observations from the Multi-Angle Imaging Spectroradiometer (MISR) instrument on Terra and near backscattering reflectances from EPIC. A canopy radiation model parameterized in terms of canopy spectral invariants underlies the theoretical basis for joining Terra MISR and EPIC data. The proposed model can accurately reproduce both MISR angular signatures acquired at 10:30 AM local solar time and diurnal courses of EPIC reflectance. Analyses of time series of the hot-spot signatures suggest the method's ability to unambiguously detect seasonal changes in equatorial forests.

[13] CATS stands for Cloud–Aerosol Transport System, which was an instrument mounted on the International Space Station and operated from 2015 to 2017.

Jan Pisek [University of Tartu/Tartu Observatory, Estonia] explored the potential of EPIC data to retrieve a *clumping index* for Australian Terrestrial Ecosystem Research Network (TERN) observing sites. Significant clumping of vegetation foliage alters the radiation environment and affects vegetation growth. Pisek obtained good quality results with an approach that used the EPIC VESDR data that correlate well with the results from previous efforts of mapping clumping index from space. This general agreement between different retrieval strategies and different input data sources—including EPIC—is important for increasing overall confidence and general validity of clumping information retrieval from space.

Other EPIC Results

Guoyong Wen [USRA/Morgan State University] developed a method to recover eclipse-affected EPIC images by using the reduced brightness of the Sun during solar eclipse, calculated from the limb darkening function. This allowed comparison of eclipse-affected images with noneclipse reflectance images at the pixel level to quantify the spectral reflectance reduction from different reflectors to provide insight into the cause of the reduction. This method was applied to EPIC images acquired during the August 21, 2017, eclipse when totality was over Casper, WY, and Columbia, MO, and the June 21, 2020, eclipse, when totality was over the Arabian Desert, the Himalayas, and Southwest China. As a result, the global average spectral as well as spectrally integrated reflectance reductions can be explained by the contribution from different reflectors (e.g., land, cloud, ocean, vegetation) in the Moon's shadow.

Joy Song [Montgomery Blair High School, Silver Spring, MD] reported on research examining EPIC images of cyclones over the Southern Ocean from December 1, 2020, to February 28, 2021. Using EPIC and MERRA-2 data, he analyzed the spatial distributions of cyclones and their tracks, as well as their strength (represented by the central pressure of the cyclone). The preliminary results show that most cyclones are distributed around the 60° S belt and that the highest cyclone density area is in the Indian Ocean sector. The cyclones that have been visually identified in this study will serve as the "ground truth" input for a future cyclone identification machine learning model.

Antti Penttilä [University of Helsinki, Finland] showed how EPIC image data can be used to derive the spherical shortwave albedo of Earth. He described a processing pipeline that runs new EPIC data daily and updates the albedo time series from the start of EPIC operations. The time series reveals interesting temporal and spatial variations in Earth's albedo. Penttilä claimed that this time series showed a systematic seasonal variation with the mean annual albedo estimated as 0.295±0.008. He also noted that an exceptional albedo maximum occurring in 2020, which he attributed to unusually abundant cloudiness over the Southern Ocean.

Nick Gorkavyi [SSAI] observed that the Moon is a unique and inspiring vantage point from which the whole Earth can be observed at its different phases. *Artemis* is a key NASA program to go back to the Moon for scientific discoveries. EPIC is a unique instrument to allow assessment of the capabilities of *Artemis* for Earth science, because it gives us the rare opportunity to see our planet as a whole. Deploying an analog of EPIC on the Moon's surface would offer a unique opportunity to image the full range of Earth's phases, observing vegetation characteristics, volcanic and mesospheric clouds, and ocean/cloud glint reflections at different phase angles.

Conclusion

At the end of the meeting **Alexander Marshak**, **Richard Eckman**, and **Adam Szabo** discussed adding content to the EPIC website: for example, daily fluctuations of different products (e.g., cloud and aerosol properties, surface reflectance, ozone), and the possibility of designing and making gridded L3 products available to the scientific community. There was also a discussion of EPIC's operational characteristics, particularly the signal-to-noise properties of bright and dark scenes.

Overall, the meeting was very successful and provided an opportunity to learn the status of DSCOVR's Earth-observing instruments, EPIC and NISTAR, the status of recently released L2 data products, and the science results being achieved from the L-1 point.

There are more and more users of DSCOVR data worldwide, and the Science Team hopes to hear from some of these users, as well as from team members at its next meeting. Be sure to check the DSCOVR website (*epic.gsfc.nasa.gov*) periodically for the latest updates from the mission.

The next STM will be held in the fall of 2022 (hopefully, in person). ■

in the news

Global Climate Change Impact on Crops Expected Within 10 Years, NASA Study Finds[1]

Ellen Gray, NASA's Earth Science News Team, ellen.t.gray@nasa.gov

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*.

Climate change may discernibly affect the production of maize (corn) and wheat as early as 2030 under a high greenhouse gas emissions scenario, according to a new NASA study published in the journal, *Nature Food*.[2] Maize crop yields are projected to decline 24%, while wheat could potentially see growth of about 17%—see **Figure**.

Using advanced climate and agricultural models, scientists found that the predicted change in yields is due to projected increases in temperature, shifts in rainfall patterns, and elevated surface carbon dioxide (CO_2) concentrations from human-caused greenhouse gas emissions. These changes would make it more difficult to grow maize in the tropics, but could expand wheat's growing range.

"We did not expect to see such a fundamental shift, as compared to crop yield projections from the previous generation of climate and crop models conducted in 2014," said lead author **Jonas Jägermeyr** [NASA's Goddard Institute for Space Studies/Earth Institute at Columbia University], who is a crop modeler and climate scientist. The projected maize response was surprisingly large and negative, he said. "A 20% decrease from current production levels could have severe implications worldwide."

To arrive at their projections, the research team used two sets of models. First, they used climate model simulations from the international Climate Model Intercomparison Project-Phase 6 (CMIP6, *https://www.wcrp-climate.org/wgcm-cmip/wgcm-cmip6*). Each of the five CMIP6 climate models used for this study runs its own unique response of Earth's atmosphere to greenhouse gas emission scenarios through 2100. These responses differ somewhat due to variations in their representations of the Earth's climate system.

Then the research team used the climate model simulations as inputs for 12 state-of-the-art global crop models that are part of the Agricultural Model Intercomparison and Improvement Project (AgMIP, *https://agmip.org*), an international partnership coordinated by Columbia University. The crop models simulate on a large scale how crops grow and respond to environmental conditions such as temperature, rainfall,

[1] **Editor's Note:** While this is the *nasa.gov* title for this article, this is not meant to suggest that climate impacts are not already occurring. As explained in the text, it is "discernible impacts" that are projected to occur by 2030.

[2] To read the study, visit *https://www.nature.com/articles/s43016-021-00400-y*.

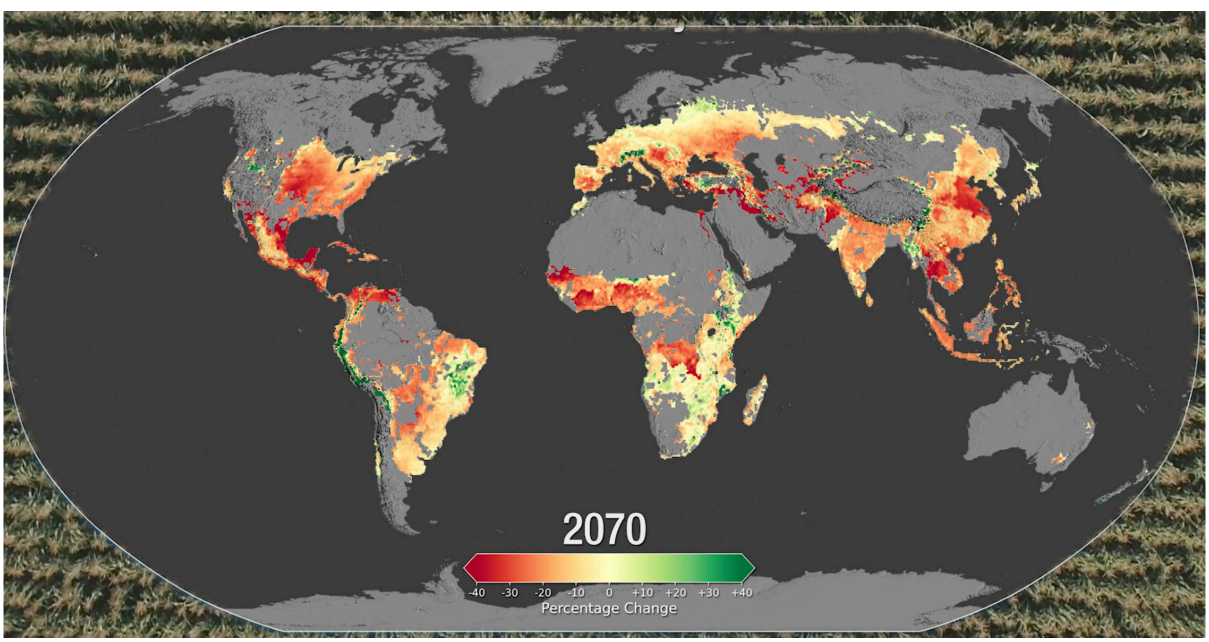


Figure. This map shows where decreases in corn yields (red) are projected to occur in 2070: parts of North America, South America, West Africa, Central Europe, India, and China. These results are narrated in a visualization at *https://svs.gsfc.nasa.gov/13979*. **Credit:** NASA/Katy Mersmann and atmospheric CO_2, which are provided by the climate models. Each crop species' behavior is based on its real-life biological responses studied in indoor and outdoor lab experiments. In the end, the team created about 240 global climate–crop model simulations for each crop. By using multiple climate and crop models in various combinations, the researchers were more confident in their results.

"What we're doing is driving crop simulations that are effectively growing virtual crops day by day, powered by a supercomputer, and then looking at the year-by-year and decade-by-decade change in each location of the world," said co-author of the study **Alex Ruane** [GISS—*Co-Director of the Climate Impacts Group*].

This study focused on climate change impacts. These models do not address economic incentives, changing farming practices, and adaptations such as breeding hardier crop varieties, although that is an area of active research. The research team plans to look at these angles in follow-up work—since these factors will also determine the fate of agricultural yields in the future as people respond to climate-driven changes.

The team looked at changes to long-term average crop yields and introduced a new estimate for when climate change impacts "emerge" as a discernible signal from the usual, historically known variability in crop yields. Soybean and rice projections showed a decline in some regions but at the global scale the different models still disagree on the overall impacts from climate change. For maize and wheat, the climate effect was much clearer, with most of the model results pointing in the same direction.

Maize is grown all over the world, and large quantities are produced in countries nearer the equator. North and Central America, West Africa, Central Asia, Brazil, and China will potentially see their maize yields decline in the coming years and beyond as average temperatures rise across these breadbasket regions, putting more stress on the plants.

Wheat, which grows best in temperate climates, may see a broader area where it can be grown as temperatures rise, including the Northern U.S. and Canada, North China Plains, Central Asia, Southern Australia, and East Africa, but these gains may level off by mid-century.

Temperature is not the only factor the models consider when simulating future crop yields. Higher levels of CO_2 in the atmosphere have a positive effect on photosynthesis and water retention, increasing crop yields, though often at a cost to nutrition. This effect happens more so for wheat than maize, which is more accurately captured in the current generation of models. Rising global temperatures also are linked with changes in rainfall patterns, and the frequency and duration of heat waves and droughts, which can affect crop health and productivity. Higher temperatures also affect the length of growing seasons and accelerate crop maturity.

"You can think of plants as collecting sunlight over the course of the growing season," said Ruane. "They're collecting that energy and then putting it into the plant and the grain. So, if you rush through your growth stages, by the end of the season, you just haven't collected as much energy." As a result, the plant produces less total grain than it would with a longer development period. "By growing faster, your yield actually goes down."

"Even under optimistic climate change scenarios, where societies enact ambitious efforts to limit global temperature rise, global agriculture is facing a new climate reality," Jägermeyr said. "And with the interconnectedness of the global food system, impacts in even one region's breadbasket will be felt worldwide." ■

NASA, ESA Partnership Releases Platform for Open-Source Science in the Cloud

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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*.

NASA and the European Space Agency (ESA) publicly released a revolutionary open-source science tool for analyzing Earth science data in the cloud–the Multi-Mission Algorithm and Analysis Platform (MAAP).[1] MAAP provides seamless access to NASA and ESA Earth science data and is a model for open-source science collaboration and analysis. As part of MAAP's initial supported area of emphasis on aboveground biomass, it is the host platform for the first globally harmonized assessment of above-ground carbon information that is vital for managing global climate change.

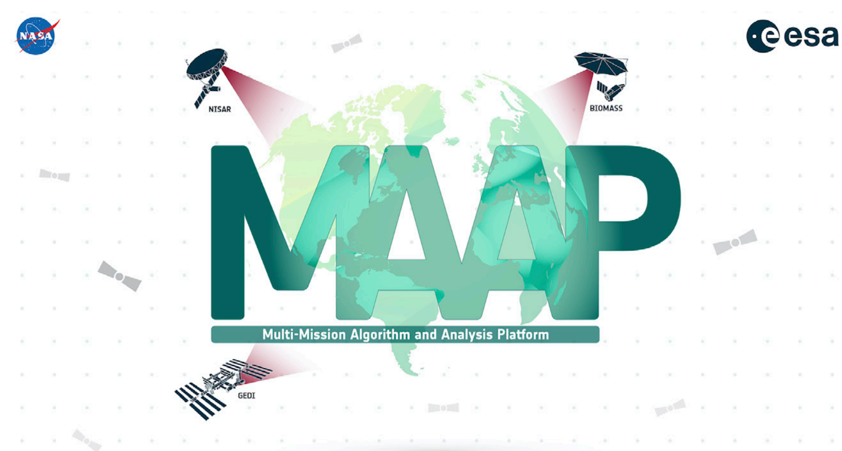
MAAP is the culmination of a two-year NASA and ESA effort and reflects the cooperation between the two agencies under the NASA and ESA Joint Program and Planning Group (JPPG) Joint Working Group (WG) on Ground Segment and Operations. MAAP is fully operational and will incrementally expand its user community over the coming months. The release of MAAP Version 2 in the Spring of 2022 will add additional data sources, allowing scientists to tackle a broader range of Earth science questions.

MAAP enables scientists to collaboratively develop algorithms and code as well as analyze and visualize large datasets acquired from sources including satellite instruments, the International Space Station, and airborne and ground campaigns. The large data volumes and high-performance computing required for MAAP, along with a shared code repository and catalog, are stored and managed in the cloud. MAAP capabilities are supported and shared between NASA and ESA.

By following open-source science principles, including full and open access to data, the use of open-source code, and unrestricted access for data users, MAAP removes barriers to participation in scientific investigation, fosters greater diversity and inclusion, and enhances opportunities for discovery.

The initial application of MAAP focuses on measurements of above-ground biomass as part of a global effort to determine the size and carbon content of Earth's forests. These data are critical for informing our understanding of climate change and forecasting its impacts and will be part of regular updates to the Intergovernmental Panel on Climate Change (IPCC). While biomass is the first application of MAAP, the platform can easily be adapted for collaborative exploration across the breadth of science data and scientific disciplines available through NASA, ESA, and similar research agencies.

MAAP currently includes data from missions such as NASA's Global Ecosystem Dynamics Investigation (GEDI) and the joint NASA/ESA AfriSAR campaign and will eventually support data from upcoming NASA and ESA missions such as ESA's Biomass mission and the joint NASA/Indian Space Research Organisation Synthetic Aperture Radar (NISAR) mission. A forthcoming connection to supercomputing facilities at NASA's Ames Research Center will enable efficient processing of extremely large MAAP global datasets, such as those expected from the NISAR mission.



The joint NASA-ESA MAAP platform enables collaborative work with data from multiple Earth observation missions. **Credit:** ESA

MAAP products can be explored on the MAAP Dashboard at *go.nasa.gov/3rm416i* or the joint platform entrance at *scimaap.net*. MAAP also can be accessed through individual NASA (*maap-project.org*) and ESA (*esa-maap.org*) landing pages. ■

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[1] To learn more about open-source science and MAAP, read "Open-Source Science: The NASA Earth Science Perspective" in the September–October 2021 issue of *The Earth Observer* [**Volume 33, Issue 5**, pp. 5-15—*go.nasa.gov/3oe8hmu*].

Instruments in the Sea and Sky: NASA's S-MODE Mission Kicks Off First Deployment

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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*.

After a successful test run in May 2021, a NASA campaign is deploying aircraft, a research vessel, and several kinds of autonomous ocean robots to study small ocean whirlpools, eddies, and currents.[1]

Using instruments at sea and in the sky, the Sub-Mesoscale Ocean Dynamics Experiment (S-MODE) team aims to understand the role these ocean processes play in vertical transport, the movement of heat, nutrients, oxygen, and carbon from the ocean surface to the deeper ocean layers below.[2] In addition, scientists think these small-scale ocean features play an important role in the exchange of heat and gases between air and sea. Understanding small-scale ocean dynamics will help scientists better understand how Earth's oceans slow some of the impacts of global warming and further affect the Earth climate system.

On October 19, 2021, the research vessel (R/V) *Oceanus*, owned by the National Science Foundation, set sail to an area 100 nautical miles out to sea off the coast of San Francisco, CA, accompanied by a fleet of several types of autonomous marine research vehicles. For the following three weeks, two aircraft will also fly repeatedly overhead to collect measurements from above while the vessel and the autonomous vehicles sample the ocean below.[3] The eyes-in-the-sky perspective from the aircraft will allow the team to monitor a large swath of ocean at once, as well as direct the research ship and autonomous ocean vehicles in the water to move toward areas of interest.

"The overall goal is to understand vertical transport in the ocean, and how the remote sensing measurements relate to the *in situ*, or 'wet,' measurements," said **Dragana Perkovic–Martin** [NASA/Jet Propulsion Laboratory (JPL)—*Radar System Engineer*].

Aerial Views of the Ocean Surface

From its vantage 28,000 ft (~8534 m) in the air aboard the NASA Armstrong King Air B200, the DopplerScatt instrument bounces radar signals off the ocean to provide information about winds and currents at the surface. The Modular Aerial Sensing System (MASS) instrument (*https://airsea.ucsd.edu/instrumentation/mass*) aboard the Twin Otter DHC6 plane flies below the clouds to observe how surface waves move and break. It collects measurements with a complex suite of laser-based and imaging devices, which allow the team to infer ocean currents from these measurements.

"The aircraft instruments provide spatial observations but can't penetrate the ocean's surface, while the autonomous vehicles and ship are providing *in situ* data that will give profiles of the ocean," said **Luc Lenain** [Scripps Institution of Oceanography at the University of California, San Diego]. Used in conjunction, these data show what is happening over an area of the ocean surface and into the depths below.

All Aboard the R/V Oceanus

While the aircraft collect data on wind, currents, and ocean properties from the sky, the ship will be taking similar measurements from the ocean surface. "Since the aircraft-based observations of ocean currents are relatively new, we want to know how they relate to our traditional ways of studying the ocean," said **Andrey Shcherbina** [University of Washington, Applied Physics Lab], who serves as chief scientist on the R/V *Oceanus*.

Photo 1. Several autonomous marine robots, including these Wave Gliders from Scripps Institution of Oceanography and the Woods Hole Oceanographic Institution, will deploy from R/V *Oceanus*. **Credit:** Laurent Grare/Scripps Institution of Oceanography

[1] To learn more about the test run, see *go.nasa.gov/2RCm2xK*.
[2] S-MODE is part of NASA's Earth Venture Suborbital-3 (EVS-3) program, and is funded by the Earth System Science Pathfinder (ESSP) Program Office at NASA's Langley Research Center and managed by the Earth Science Project Office (ESPO) at NASA's Ames Research Center.
[3] **UPDATE:** This NASA News story was published October 26, 2021. At that time the S-MODE flights had not yet taken place. Hence the use of future tense in this article. The campaign has subsequently been successfully completed.

Photo 2. A type of autonomous marine robot called a Saildrone being deployed from Alameda, CA. **Credit:** NASA/Jesse Carpenter

The ship will also serve as a launching point for a small fleet of several types of autonomous ocean vehicles. Four *Wave Gliders*—essentially surfboards with a suite of scientific instruments aboard—will bob up and down on the surface to propel themselves around the study area—see **Photo 1** on page 35. Several *Saildrones*—autonomous marine robots—will sail from San Francisco Bay to join the fleet collecting data at the study site—see **Photo 2**. The Saildrones and Wave Gliders will measure a vast array of factors such as ocean currents, wind speed and direction, air and water temperature, salinity, dissolved oxygen, and chlorophyll content.

Two kinds of trackers will float freely in the water, providing information about where and how currents are moving and interacting. The drifters remain on the surface, while the Lagrangian Floats follow the underwater ocean currents in three dimensions.

With all these instruments working in coordination with each other, with the vessel, and with the aircraft, the team hopes to capture rapidly shifting ocean currents and properties within the study area. "Our best bet is to have a lot of instruments sampling this small patch of ocean so that we have a comprehensive multifaceted view," said Shcherbina. From these data, the team hopes to learn more about small-scale ocean movements and how these movements may move heat, nutrients, and gases within the ocean and between air and sea. ■

Jack Kaye Receives 2021 Presidential Rank Award

Jack A. Kaye [NASA Headquarters—*Associate Director for Research, Earth Science Division (ESD) within NASA's Science Mission Directorate (SMD)*] was selected by U.S. President Joe Biden to receive a 2021 *Meritorious Presidential Rank Award*. These awards are considered the highest honor a career civil servant can receive in recognition of significant professional, technical, and/or scientific achievements and for unrelenting commitment to public service.

The Civil Service Reform Act of 1978 established the Presidential Rank Awards Program to recognize a select group of career members of the Senior Executive Service (SES) for exceptional performance over an extended period. Two categories of Presidential Rank are available: Distinguished and Meritorious. Jack won the Meritorious Executive award, bestowed upon the top 5% of those eligible for this award category.

Jack has been a member of the SES since August 1999, when he began managing NASA's Earth Science Research Program. Earlier positions in his more than 38-year career at NASA include being a space scientist at NASA's Goddard Space Flight Center and manager of the Atmospheric Chemistry Modeling and Analysis Program at NASA Headquarters.

The staff of *The Earth Observer* extend congratulations to Jack, who is highly deserving of this top-tier recognition bestowed by the President.

The complete list of the Presidential Rank Awards, which includes a *Distinguished Award* for **Thomas Zurbuchen** [NASA HQ—*Associate Administrator, Science Mission Directorate*] and awards for other NASA personnel, may be found on the U.S. Office of Personnel Management website at *www.opm.gov/policy-data-oversight/senior-executive-service/presidential-rank-awards/2021*.

NASA Earth Science in the News

Ellen Gray, NASA's Goddard Space Flight Center, Earth Science News Team, ellen.t.gray@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*.

NASA Greenlights Study of Tropical Storms, November 14, *washingtonpost.com*. A new NASA Earth science mission, dubbed Investigation of Convective Updrafts (INCUS), will take measurements of the water vapor and warm air pumped into the atmosphere, that forms clouds and fuels extreme weather, helping researchers learn more about storm formation. In 2027 the agency will launch three satellites that will circle Earth in a close formation and feed measurements to researchers on the ground. Researchers say that better measurements could lead to a better sense of storm mechanics. The observations "will better prepare us for predictions of extreme weather in current and future climates," states **Susan van den Heever** [Colorado State University—*INCUS Principal Investigator*].

Kamala Harris Visits NASA to View Climate Change Studies, November 10, *econotimes.com*. **Vice President Kamala Harris** is the chair of the National Space Council. As part of the efforts to further raise awareness of climate change, Harris visited NASA's Goddard Space Flight Center (GSFC) to look at the agency's climate change studies. She toured the facility as part of the Biden administration's efforts to raise awareness and combat the growing threat of climate change. **NASA Administrator Bill Nelson** unveiled the first images from the Landsat 9 satellite, a joint mission of NASA and the U.S. Geological Survey, that launched in September—see **Photo 1**. During her visit, Harris delivered remarks to the agency's employees, thanking them for their contributions to the country and the world. "I truly believe space activity is climate action. Space activity is education. Space activity is also economic growth. It is also innovation and inspiration. And it is about our security and our strength," she said. "When it comes to our space activity, there is limitless potential...So, as we go forth from here, let us continue to seize the opportunity of space." Harris and Nelson discussed the agency's announcement of the new Earth Venture Mission-3, with the Investigation of Convective Updrafts (INCUS) set to study how tropical storms and thunderstorms develop and grow to improve weather and climate models (see article above).

Photo 1. Vice President Kamala Harris shares her enthusiasm, alongside **Dennis Andrucyk** [NASA's Goddard Space Flight Center—*Center Director*] and **NASA Administrator Bill Nelson**, for the results of current satellite missions, using the Hyperwall at NASA's Goddard Space Flight Center on November 5, 2021. The Hyperwall visualizes Earth Science data for better understanding. **Credit:** NASA/Taylor Mickal

Can NASA Help Save the Planet? Yes, with Indigenous Partners, November 9, *thehill.com*. In the fall of 2020, at the height of the COVID-19 pandemic, NASA came out with the Drought Severity Evaluation Tool, jointly developed with the Navajo Nation Department of Water Resources.[1] NASA tracks water supply on planet Earth and has a longstanding mandate to "use the vantage point of space to understand our home planet, improve lives, and safeguard the future." The Indigenous People's Capacity Building Initiative, launched in 2017 by **Cindy Schmidt** [NASA's Ames Research Center (ARC)—*Associate Program Manager of the Ecological Forecasting Program*], provides a template for giving Indigenous communities the technical know-how to make urgent, climate-related decisions. It rests on three principles: geospatial training, community engagement, and co-production of knowledge. The drought tool, funded by NASA's Western Water Applications Office, is a case in point. Jointly built by **Carlee McClellan** [Navajo Nation Department of Water Resources] and **Amber McCullum** [ARC], the tool combines satellite data and rain-gauge data to pinpoint specific needs within administrative subunits,

[1] To learn about this tool, visit *go.nasa.gov/3peYICX*.

giving the Navajo the precise information needed to plan for the exploding problem of water scarcity. NASA also stands to gain. "Engaging with the Navajo Nation and other Indigenous communities allows us to see all aspects of planet Earth as connected," McCullum said, and continued, "Indigenous knowledge systems [are] invaluable to all Earth scientists, especially at NASA."

Photo 2. Ready for flight, **Hector Torres Gutierrez** [NASA/Jet Propulsion Laboratory] and **Delphine Hypolite** [University of California, Los Angeles] are ready to board the King Air B200 for the first S-MODE pilot campaign flight. **Credit:** NASA

***NASA Launches Ocean Research Mission off San Francisco**, Issue 21, *oceanographicmagazine.com*. About 160 km (100 mi) off the coast of San Francisco, CA, the organization better known for its space programs is trying to find out in what way oceans are involved in climate change. As part of the mission, NASA has one ship, two airplanes, numerous robotic research vehicles, and Saildrones involved. During the mission, which ran until November 6, the team of scientists sought to research the ocean surface with its many whirlpools and eddies because they believe that these play a crucial role in the transfer of gases and heat between the ocean and the atmosphere. Called the Sub-Mesoscale Ocean Dynamics Experiment (S-MODE, *go.nasa.gov/31eNbvh*), the mission wants to further research at submesoscales–ocean dynamics that are smaller than 10-km (~6.2-mi) across, such as ocean surface eddies, known to have an important effect on the climate. Because eddies are difficult to study by satellite due to their small size, the S-MODE mission utilizes a variety of different instruments closer to the eddies. The site off San Francisco was chosen because it is located on the California Current, which is known for its ocean eddies. While two aircraft collect data on wind and ocean surface currents from different heights, the ship and research vehicles collect images and measurements in the waterwater (Photo 2 shows the King Air B200 aircraft in the background). Ultimately, the team hopes to find out more about the involvement of eddies in slowing down the impact of climate change. **Tom Farrar** [Woods Hole Oceanographic Institution—*S-MODE Principal Investigator*] said in a press briefing: "The goal is to map out a full [three-dimensional] structure." The findings will support an international NASA project that is planned for next year. It will be the first survey of all bodies of water, including lakes and rivers, on the planet. "Observing ocean circulation directly from space would be a huge leap forward for science," said **Nadya Vinogradova-Shiffer** [NASA Headquarters—*Director of the Ocean Physics Program*].

***Climate Change Will Start Impacting Global Supply of Corn and Wheat as Early as 2030, NASA Study Finds**, November 2, *cbsnews.com*. Global crop supplies are facing a grim future because of climate change. New research from NASA shows that by the end of the century, the availability of corn, wheat, soybeans, and rice are projected to look drastically different from today—and that the world will start feeling the implications as early as 2030. The study, in the journal *Nature Food*, used advanced climate and agricultural models to analyze the future of global food production.[2] Over the next decade, the projected increases in temperature, changes in rainfall patterns, and increased surface carbon dioxide concentrations will change agriculture around the world. "Major shifts in global crop productivity due to climate change are projected to occur within the next 20 years," the study says, "several decades sooner than estimates based on previous projects." Among the most dire of their findings was that corn crop yields are projected to decline by a quarter (25%) by the end of the century under a high greenhouse gas emissions scenario. This kind of decline, researchers said, could "have severe implications worldwide." Corn—the "most important global crop in terms of total production and food security," according to the study—will become more difficult to grow in the tropics, researchers found. Lead author **Jonas Jägermeyr** [NASA's Goddard Institute for Space Studies] said in a statement that such a decline is surprisingly large and negative. Central Asia, the Middle East, southern Europe, the western U.S., and tropical South America are expected to start seeing corn yield declines before 2040, the researchers found. "We did not expect to see such a fundamental shift, as compared to crop yield projections from the previous generation of climate and crop models conducted in 2014," Jägermeyr said. "A 20% decrease from current production levels could have severe implications worldwide." Soybeans and rice are also projected to decrease in some areas, although the researchers' models have not yet agreed on the impact this will have globally.

*See News Story in this issue.

[2] To read the study, visit *www.nature.com/articles/s43016-021-00400-y*.

Earth Science Meeting and Workshop Calendar

NASA Community

March 21–25, 2022
Ocean Surface Topography Science Team Meeting, Venice, Italy.
ostst-altimetry-2022.com

April 18, 2022
Land Cover Land Use Change Science Team Meeting, Bethesda, MD

May 16–20, 2022
2022 Sun–Climate Symposium, Madison, WI
lasp.colorado.edu/home/meetings/2022-sun-climate-symposium

Global Science Community

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

February 16–17, 2021
Our Ocean Conference, Palau
ourocean2022.pw

February 27–March 4, 2022
Ocean Sciences Meeting, *virtual*
osm2022.secure-platform.com/a

March 7–11, 2022
Global Council for Science and the Environment, *virtual*
www.gcseglobal.org/conference

April 19–30, 2021
EGU General Assembly, *virtual*
www.egu21.eu

April 22, 2022
Earth Day, TBD

August 2021
AOGS 18th Annual Meeting, *virtual*
www.asiaoceania.org/aogs2021/public.asp?page=home.html

Code 610
National Aeronautics and Space Administration

Goddard Space Flight Center
Greenbelt, MD 20771

eospso.nasa.gov

The Earth Observer

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

Article submissions, contributions to the meeting calendar, and other suggestions for content are welcomed. Contributions to the calendars should contain date, location (if meeting in person), URL, and point of contact if applicable. Newsletter content is due on the weekday closest to the first of the month preceding the publication—e.g., December 1 for the January–February issue; February 1 for March–April, and so on.

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NP-2021-12-717-GSFC