Over Thirty Years Reporting on NASA's Earth Science Program

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The Editor's Corner

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This summer, NASA brought its **Student Airborne Research Program** (SARP) to the East Coast for the first time. SARP focuses on having undergraduate students conduct integrative Earth System Science observations that incorporate the approaches, tools, and philosophy of NASA's Earth Science Division (ESD). SARP-East (E) began in June and continued through July, engaging 22 high-performing STEM undergraduate students from colleges nationwide in a real-world NASA research campaign—see **Photo 1**, below, and **Photo 2** on page 3.

Several governmental, academic, commercial, and non-governmental institutions contributed to this experience for the undergraduate participants, as well as for the five graduate mentors and seven faculty mentors.[1] This intensive residential program was based out of the Christopher Newport University (CNU) in Newport News, VA, with an immersive two-week, residence-based field research experience taking place at Virginia Commonwealth University's (VCU) Rice Rivers Center. SARP-E was supported by personnel from GSFC and LaRC, with substantial support from the ESD Research and Analysis Program and its associated Earth Sciences centers.

SARP-E employs an interdisciplinary approach to data gathering and analysis. Thematic aspects are summarized in the phrase: "Surf, Turf, Above the Earth, and How Things Fit Together." Instrumented systems were used on land (e.g., soil moisture), in water (e.g., biology, salinity), and in the air (*in situ* and remote sensing). Airborne platforms included the LaRC B-200 active remote sensing platform (the "Pinger"), the Dynamic Aviation B-200 *in situ* platform (the "Sniffer"), and the LaRC SR-22 passive remote sensing platform (the "Looker"). Space-based assets were used to augment the local-scale perspective to provide context for a community-relevant analysis. Data analyses and syntheses utilize principles of NASA Open Science and, to the extent possible, with a cloud-based analytical environment. Final student presentations were given at CNU on July 28, 2023. Kudos to **Bob Swap** [GSFC—*SARP-E Program Director*], **Melissa Yang Martin** [NASA

[1] In addition to NASA, federal government participants include the EPA, NRL, USDA, and USACE. Academic institutions include CNU, VCU, Hampton University, Virginia Institute of Marine Science, the College of William & Mary, the University of Virginia, and James Madison University. Key additional contributors and participants include Dynamic Aviation based in Bridgewater, VA, and the Pamunkey and Chickahominy Tribes,

continued on page 2

Photo 1. For the first time, NASA brought its Student Airborne Research Program to the East Coast with the help of Virginia Commonwealth University faculty and the team at VCU's Rice Rivers Center. SARP-East, which runs from June through July, engages undergraduate students from colleges nationwide in a real-world NASA research campaigns. **Image credit:** Allen Jones/Enterprise Marketing and Communications

In This Issue

HQ, ESD—*Overall SARP Program lead*], **Barry Lefer** [NASA HQ, ESD—*Tropospheric Composition Program Manager*], and **Jack Kaye** [NASA HQ, ESD—*Associate Director for Research*], along with the entire team, for conceiving, organizing and supporting this summer's SARP-E campaign.

This year, the **AErosol RObotic NETwork** (AERONET) program marked 30 years of continuous aerosol measurements. This represents an exemplary model of international collaboration. AERONET is a federated network of individual and institutional partners consisting of identical ground-based Sun and sky radiometers whose measurements are processed to generate aerosol optical properties, e.g., spectral aerosol optical depth (AOD) and particle size distribution (PSD). The network began at GSFC in May 1993 at the start of the EOS Program and quickly expanded to sites in Senegal, France, Canada, and Brazil within months. Through international collaboration, AERONET currently supports approximately 600 active sites across more than 100 countries, plus temporary sites used for field campaigns.

Participating sites adhere to strict quality-control protocols. Moreover, the instruments used in the network are regularly calibrated against standards, allowing for intercomparison of data between different sites and over long time periods, thereby enabling researchers from various institutions around the world to access and utilize the data with confidence.

For NASA and the atmospheric remote sensing community, AERONET measurements are the "gold standard" for validating and improving satellite-based remote sensing techniques for aerosol monitoring and global and regional model evaluation and forecasts. Beyond research activities, the data generated by the AERONET program have found numerous applications that derive from their atmospheric measurements.

After **Brent Holben** [GSFC—*AERONET Founding Project Scientist*] retired in 2022, **Pawan Gupta** and **Elena Lind** [both at GSFC] became project co-leads. On behalf of the Earth science community, I express our thanks and gratitude to Holben for his extraordinary three decades of AERONET leadership.

Moving from the ground to Earth orbit, we report the end of a long-time member of the International **Afternoon Constellation**, or "A-Train" of Earth observing platforms. NASA and the **Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation** (CALIPSO) team agreed to end the CALIPSO science mission on August 1, 2023. This mission has been highly successful: designed for a lifetime of 3 years, CALIPSO delivered unprecedented measurements of the vertical structure of the Earth's atmosphere for 17 years. Fuel reserves are now exhausted, and in its decaying orbit the satellite can no longer generate sufficient power to operate the science instruments. Both agencies thank the international data user community for their on-going interest and support. Over the next two years, the project will continue to refine and document its extensive data products catalog and will notify the community as these products are updated. More information is available through a **statement on the CALIPSO webpage** and from a **CNES press release**.

The **Sentinel-6 Michael Freilich** (S6MF) satellite, launched in November 2020 and replaced Jason-3 as the reference mission for measuring sea level in April 2022. The S6MF satellite has demonstrated excellent performance thus far, and continues to meet all science and operational requirements. Following a thorough assessment of the data quality by the mission team and

Photo 2. NASA SARP-East participants and scientists conducted flyovers from Newport News/Williamsburg International Airport to collect data on the environment around VCU Life Sciences' Rice Rivers Center. **Image credit:** Virginia Commonwealth University (VCU)

a small community of experts, the first data from the satellite were released publicly—starting from June 2021. Approximately a year later, in July 2022, a first full-mission reprocessing of data products from the satellite was released to the public. Another reprocessing of the entire data set is currently underway and is planned to be released sometime during the summer of 2023. Among the data released are the *near-real-time data*, which become available within 3 hours of collection; the *short time critical data*, which are released within 36 hours; and the *non-time-critical data*, which are released after about 60 days. While the near-real-time data are quite accurate (about 6 cm accuracy), longer latency allows for increasingly accurate measurements of sea level. The non-time-critical data are the most accurate—with an accuracy of about 3 cm for a single measurement—and can measure globally averaged sea level with an accuracy of a few millimeters. This provides continuity with the global mean sea level observations that started in the early 1990s with the Ocean Topography Experiment (TOPEX)/Poseidon mission, followed by Jason-1, Jason-2, and Jason-3.

S6MF's successor, **Sentinel-6B**, successfully completed testing in mid-2022. During October 2022 the satellite was placed into storage, with launch planned for November 2025. A third satellite, Sentinel-6C, has been proposed to extend the Sentinel-6 reference mission further, to 2036. To learn more about these and other topics related to S6MF and other ocean topography missions, see the Ocean Surface Topography Science Team Meeting summary on page 19 of this issue.

The **Stratospheric Aerosol and Gas Experiment** (SAGE) has been taking observations from the International Space Station [SAGE III/ISS] since 2017. Recently, ISS partners agreed to extend operations of ISS through 2030, with the flight manifest showing SAGE III/ISS as the only external payload occupying its current location on the Express Logistics Carrier (ELC)-4. SAGE III is currently waiting for results from the Earth Science Senior Review—the regular *Earth Science Division Review* of Operating Missions–that should be announced soon.

With over 50,000 solar occultations successfully acquired since becoming operational in July 2017, the SAGE III/ISS payload continues to operate nominally. The Multipurpose Laboratory Module (MLM), or *Nauka*, replaced the *Pirs* module in July 2022, allowing the SAGE payload to position the scan head to the proper orientation to collect more science data events over the nominal range of ISS attitudes.[2]

Last fall, the SAGE III/ISS Science Team Meeting took place October 13–14, 2022, at LaRC. **Jun Wang** [University of Iowa—*SAGE III/ISS Science Team Lead*], **David Flittner** [LaRC—*SAGE III/ISS Project Scientist*], and **Richard Eckman** [NASA Headquarters (HQ)—*Program Scientist*] guided discussions on the status of the mission, instrument operations, data processing, and the latest scientific findings from studies that used

[2] When the SAGE III/ISS payload launched in 2017, its configuration was designed with plans for MLM to be installed sooner than 2022, causing the ISS orientation to be near the edge of SAGE III's pointing system envelope.

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

ASI	Agenzia Spaziale Italiana
CNES	Centre National d'Études Spatiales
EPA	U.S. Environmental Protection Agency
GSFC	NASA's Goddard Space Flight Center
ISRO	Indian Space Research Organisation
LaRC	NASA's Langley Research Center
NRL	U.S. Naval Research Laboratory
ROSES	Research Opportunities in Space and Earth Sciences
STEM	Science, Technology, Engineering, and Mathematics
USACE	U.S. Army Corp of Engineers
USDA	U.S. Department of Agriculture

Photo 3. Students and scientists from NASA's Goddard Space Flight Center launch an ozonesonde. Shortly after the launch, the team studied the data the balloon collected, detecting higher levels of pollution in the atmosphere as smoke from wildfires in Canada drifted over the East Coast. **Image credit:** VCU

the various SAGE III data products of ozone (O_3), aerosol, water vapor, nitrogen dioxide (NO_2), and nitrogen trioxide, or nitrate (NO_3). To read about the SAGE III/ISS Science Team Meeting, turn to page 11 of the issue. The first "off-center" ROSES SAGE III/ISS Science Team Meeting will be held September 12–13, 2023, on the campus of Georgia Tech in Atlanta, GA. Science results of all aspects of SAGE will be presented, including the ongoing impacts of the 2022 eruption of Hunga Tonga–Hunga Ha'apai volcano.

Also on ISS, the **ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station** (ECOSTRESS), originally launched in 2018 as a one-year mission, was recently approved to remain at the same location on the ISS through FY2029 via an out-of-cycle Senior Review process to accommodate the decision timeline required by the ISS. With this extension, ECOSTRESS will continue to provide vital data for a wide range of science and applications. The extension will also enable potential overlap with the Thermal Infrared element of the Surface Biology and Geology (SBG) mission scheduled for launch later this decade. SBG is a joint project with the ASI (the Italian Space Agency) and NASA—and part of the planned **Earth System Observatory**.

Researchers continue to develop new science and applications for ECOSTRESS data, with numerous studies on urban heat impacts, mitigation strategies, and even studies related to the social justice implications of these climate issues. The Land Processes Data Active Archive Center (LP DAAC), which hosts ECOSTRESS data, has also seen significant demand, with ECOSTRESS land surface temperature and evapotranspiration products among the top five most requested products over the past year. ECOSTRESS has implemented a small calibration correction as well as other algorithmic updates, and Collection 2 products for radiance, geolocation, and land surface temperature are now available for users. The next ECOSTRESS science team meeting will be held in Ventura, CA, October 17–19, 2023. Information and registration is available through the **ECOSTRESS website**.

Calling attention to two other items discussed in the current issue, on June 21, 2023, there was a ribbon-cutting ceremony led by **NASA Administrator Bill Nelson** at the Mary W. Johnson NASA Headquarters building to officially open the **Earth Information Center** (EIC), where visitors are invited to see Earth the way NASA views it from space. The EIC is both a physical space (at NASA HQ) and a web-based experience. The physical space includes a Hyperwall presentation that tells the story of our planet through videos and visualizations on subjects like air pollution, agriculture, and hurricanes. It also includes dashboards with real-time data and imagery of our planet. See the news story on page 24 of this issue to learn more about the EIC, including a full list of the other government organizations collaborating with NASA on the EIC.

Finally, for the second time, NASA participated in the **Commodity Classic** event, held March 9–11, 2023, in Orlando, FL, and online. The meeting is the largest farmer-led, farmer-focused, educational, and agricultural experience in the U.S. and provides an opportunity to showcase NASA's vast environmental data resources. Based on such data, NASA and its many domestic and international partners work together to find the best ways to rethink and reshape our food and agriculture systems and place data-driven management tools into the hands of farmers.

Commodity Classic 2023 marks yet another successful hybrid enterprise for NASA exhibits, with participants able to engage from anywhere in the world via the virtual exhibit platform. In-person attendance was record-breaking with over 10,400 attendees, (4572 of which were farmers,) as well as exhibitors, industry stakeholders and members of the media gathered for the 2023 Commodity Classic event. Turn to page 5 of this issue to learn more about NASA's participation in the 2023 Commodity Classic. ■

From Low Earth Orbit to the Kitchen Table: NASA Earth Science Data Continues to Serve America's Farmers

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Introduction

What we observe from above impacts every aspect of our lives on the ground, from food supplies to safety and health. Real-time or near-real-time, reliable, openly accessible information on agricultural production prospects are critical for shaping agricultural policies and averting food crises.

For decades, NASA has studied Earth's systems from the unique vantage point of space, currently drawing Earth observations from 24 missions in orbit around the planet. The applications that NASA produces, such as NASA Harvest's precision nutrient management tools, OpenET, and Crop-CASMA[1] are designed to put data-driven management tools into the hands of farmers.

NASA builds detailed, high-resolution crop models based on an ensemble of Earth science data products. From simulated corn and soybean yields to soil moisture observations and forecasts, NASA crop and climate model predictions provide farmers with essential information about commodity crops.

Scientists at NASA and its partner agencies use these models to project changes in temperature, track shifts in rainfall patterns, and detect elevated levels of surface carbon dioxide (CO_2) concentrations to help them form a more complete picture of how the production of commodity crops respond to weather, soil type, soil conditions, farm management, and cultivar traits. Farmers and others regularly make decisions about water management, planting, and market decisions based on NASA data delivered by partner agencies and organizations, e.g., the **U.S. Department of Agriculture** (USDA). Based on such data, NASA and its many domestic and international partners work together to find the best ways to rethink and reshape our food and agriculture systems.

NASA and its many domestic and international partners work together to find the best ways to rethink and reshape our food and agriculture systems.

For the second time, NASA participated in the **Commodity Classic** event, this one was held March 9–11, 2023, at the Orange County Convention Center's West Concourse exhibit hall in Orlando, FL—and online everywhere. Describing itself as being *"Created by farmers for farmers,"* this meeting is the largest farmer-led, farmer-focused, educational, and agricultural experience in the U.S. In-person **attendance was record-breaking**: Over 10,400 attendees (4,572 of which were farmers), including exhibitors, industry stakeholders, and members of the media, gathered for the 2023 Commodity Classic event. Agency representatives, including **Karen St. Germain** [NASA Headquarters—*Director of NASA's Earth Science Division*], attended the meeting in person to discuss information, tools, and resources drawn from NASA's Earth-observing satellites and scientific research. St. Germain participated in various speaking events and meetings and delivered a presentation at the NASA exhibit in front of the Hyperwall titled "Exploring the Value of Partnerships: NASA and American Agriculture"—see **Photo 1** on page 6.

[1] To learn more about these NASA applications, see **"NASA Earth Science Data: A Valuable New Commodity for America's Farmers"** in the March–April 2022 issue of *The Earth Observer* [**Volume 34**, **Issue 2**, pp. 4–10].

Photo 1. Karen St. Germain [NASA HQ—*Director of the Earth Science Division*] spoke in front of the Hyperwall at the in-person NASA exhibit at the Commodity Classic event. During the meeting, St. Germain and other NASA representatives interacted with farmers and others in attendance to learn more about their needs and how the agency's current and future data resources might be able to help address those needs. **Photo credit:** NASA

Commodity Classic 2023 marks yet another successful hybrid enterprise for NASA exhibits, with participants able to engage from anywhere in the world via the virtual exhibit platform. Staff from NASA's Science Support Office (SSO) traveled to support in-person activities at the NASA booth while other SSO staff members supported the online component.

In NASA's Virtual Event Platform, *NASA Science Now*,[2] online participants explored the connection between NASA Science and agriculture from across the globe. In coordination with **NASA's Applied Sciences Program**, SSO staff designed and oversaw the virtual exhibit, offering technical and logistical support as needed. The following summary describes NASA's participation in both the virtual and in-person domains of the hybrid Commodity Classics event.

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Welcoming Remarks

NASA Administrator Bill Nelson and **Brad Doorn** [NASA Headquarters—*Director of NASA's Water Resources and Agricultural Program*] both provided recorded welcoming remarks for Commodity Classic 2022 that were reused for the 2023 event. The Administrator's presentation was shown during the in-person meeting to introduce **U.S. Secretary of Agriculture Tom Vilsack**, who gave the keynote address. Both presentations were accessible via the virtual exhibit.[3]

Nelson's presentation focused on how NASA's Earth-observing satellites provide unique vantage points from space that enables continuous global observations of Earth's various systems, how they behave, and how they interact over long periods of time—which is key to studying climate. Nelson stressed that collaboration is at the core of NASA's efforts—which is why NASA supports events like the Commodity Classic event. Through its collaboration with the USDA and other organizations, NASA provides farmers and industry with essential data for crop reports, drought assessments, extreme weather prediction, and—eventually—predicting the impact of climate change on the food supply.

Doorn also welcomed participants to the meeting, focusing his remarks on the capabilities afforded by the virtual exhibit. He gave a quick overview of the content of the five "rooms" and noted that NASA's goal is to develop tools needed to work toward a more sustainable, resourceful, and profitable agricultural industry in the U.S. Toward that end, Doorn emphasized that NASA seeks feedback from participants at the

[2] To learn more about NASA's Virtual Event Platform, *NASA Science Now*, see **NASA Unlocks Secrets of the Universe at the 2022 AGU Fall Meeting** in the January–February 2023 issue of *The Earth Observer* [**Volume 35**, **Issue 1**, p. 10].
[3] Nelson's and Doorn's remarks were the same as those that were given at the 2022 Commodity Classic. To read Nelson's full remarks and learn more about the 2022 meeting, see page 5 of the article referenced in footnote 1.

Commodity Classic event (both in person and virtual) about what more the agency can do to support agricultural activities. He concluded by saying, "From seed to market, NASA supports our nation's agricultural industry," and he encouraged participants to enjoy exploring the in-person and virtual exhibits.

Overview of Meeting Elements

Once registered, NASA employees used their NASA Personal Identification Verification (PIV) card, while non-NASA employees provided an email address and password to gain access to the virtual exhibit. They entered via the lobby area, which had seven options that allowed them to explore the virtual content—see **Figure**, *below*.

Figure. A screenshot of the *Home* lobby area for NASA's virtual exhibit at the Commodity Classic event. **Image credit:** NASA

A *Help Desk* button provided links to chatrooms, where participants could interact in real time with NASA scientists during certain hours, and access website technical support.

A *Useful Info* briefcase button gave participants access to key information about the meeting in one convenient location. The briefcase included links to a *Commodity Classic Event How-To Guide* that covered how to register for, enter, and navigate the virtual exhibit, and a brief one-minute overview presentation called *NASA and Agriculture: From Seeds to Satellite*. There were also links to the welcoming words from Nelson and Doorn, as summarized in the previous section.

Each of the other five buttons in the Home lobby area of the virtual exhibit led to a room with information about various aspects of NASA and its support of applications related to agriculture. These rooms included: Science Theater, NASA + Agriculture, Agriculture Data, Learning Area, and Get Involved. This being a hybrid meeting, some of the content of these online rooms overlapped with elements of the in-person exhibit. The subsections that follow elucidate these connections.

Hyperwall (In-Person)

As has been the case at most in-person meetings where it has been installed, NASA's Hyperwall—a nine-screen video wall—was the centerpiece of the in-person NASA exhibit. There was a full schedule of speakers throughout the three days of the meeting, and the frequent use of high-resolution imagery was always a draw for people who were otherwise just passing through the exhibit hall. See **Table 1** on page 8 for a list of presentations.

Table 1. List of Hyperwall (in-person) and/or Science Theater (virtual) Presentations and Speakers at the Commodity Classic event. Links are provided to those presentations that have material posted online.

Title	Presenters(s) Affiliation(s)
NASA and Agriculture: From Seeds to Satellite	[Summary Video]
Farmer Derek	**Derek Klingenberg** [Klingenberg Farm, *Peabody, KS*]
NASA Supports Advances in Agriculture Monitoring and Forecasting	**John Bolten** [NASA's Goddard Space Flight Center]
Monitoring Weather Extremes from Space	**Chris Hain** [NASA's Marshall Space Flight Center]
New NASA Acres Consortium Grows NASA Investment in U.S. Agriculture	**Alyssa Whitcraft** [University of Maryland (UMD)/Acres]
Exploring the Value of Partnerships: NASA and American Agriculture	**Karen St. Germain** [NASA Headquarters (HQ)]
No Quick Fixes: How Technology Brings Sustainability to Midwest Farms	**Laura Gentry** [Illinois Corn Growers]
Cracking the Nitrogen Code: the Power of Remote Sensing	**Laura Thompson**, [University of Nebraska, Lincoln (UNL) Extension]
What Does Digital Farming Look Like?	**Laila Puntel** [UNL Extension]
Panel: NASA Information to Support Climate Resilience Today and in the Future	**Alex Ruane** [NASA Goddard Institute for Space Studies], **Lance Lillibridge** [Iowa Corn Growers Association], **Brandon Hunnicutt** [National Corn Growers Association], and **John Farner** [Netafim Irrigation, *Frederick, MD*]
GEOGLAM Global Crop Monitor: EO Can Reduce Market Price Volatility	**Mike Humber** [UMD/Harvest]
Two Decades of Mapping U.S. Corn Yields Using MODIS	**Arthur Rosales** [U.S. Department of Agriculture's National Agriculture Statistics Service (NASS)]
The Role of Landsat Imagery for Mapping Crop Types Across the U.S.	**Rick Mueller** [NASS]
AI-Empowered Cross-Scale Sensing for Sustainable Agriculture	**Sheng Wang** and **Kaiyu Guan** [both from University of Illinois–Urbana Champaign]
Plant Disease Sensing: Studying Plant–Pathogen Interactions	**Katie Gold** [Cornell University]
NASA Harvest's Ukraine Response	**Mike Humber** [UMD/Harvest]
NASA Agriculture - Past and Future	**Brad Doorn** [NASA HQ]

Science Theater (Virtual)

Essentially the equivalent of the Hyperwall in the virtual exhibit, the Science Theater contained four prerecorded online presentations, which are linked in Table 1 along with the list of in-person Hyperwall presentations. In addition to these presentations, there was another link to the **NASA and Agriculture: From Seeds to Satellite** summary video, which was also included in the Useful Info briefcase.

Learning Area (In-Person and Virtual)

There was both an in-person Learning Area at the NASA booth (see **Photo 2** on page 10) as well as a dedicated room in the virtual exhibit for recorded presentations. The in-person and recorded Learning Area presentations are listed in **Table 2**, below. The virtual Learning Area room was organized around four topics related to Agriculture: Crop Health, Soil Moisture, Crop Monitoring, and Weather. Each topic linked to a prerecorded presentation, and the four virtual Learning Area topics are mapped to a related in-person presentation in Table 2.

Table 2. List of In-Person and Recorded Learning Area Presentations, Corresponding Virtual Learning Area Topics, and Speakers. Links are provided to those presentations that have material posted online.

Title (Corresponding Virtual Exhibit Topic)*	Presenter and Affiliation
Landsat for Crop Health (Crop Health)	**Mike Taylor** [GSFC]
OpenET* for Irrigation Scheduling (Soil Moisture)	**Jon Chilcote** [USDA's Natural Resources Conservation Service]
Daymet: GIS for Weather Monitoring (Weather)	**Michele Thornton** [Oak Ridge National Laboratory Distributed Active Archive Center]
Explore Earth's Land, Water, and Vegetation with NASA Worldview (Weather)	**Elizabeth Joyner** [NASA HQ]
NASA Harvest's Open Access Agricultural Monitoring Dashboards (Crop Monitoring)	**Mike Humber** [UMD/Harvest]
OpenET:* Supporting Irrigation Decisions	**Forrest Melton** [NASA's Ames Research Center]
Systems to Grow Plants on Earth and Beyond	**Joan Harper-Neely** [NASA HQ]

* OpenET stands for *open evapotranspiration*.

NASA + Agriculture (Virtual)

This room contained links to several fact sheets that illustrated how NASA data are being connected to different agricultural applications. Each fact sheet included several images with captions and links to videos. The options included: Land + Crops, Water Management + Drought, Weather + Changing Extremes, Conservation + Carbon, Markets + Farm Economics, and Latest NASA + Agriculture News. This last link was not to a fact sheet like the others in this room, but instead included links to recent news articles at various NASA websites having to do with NASA's involvement in agriculture.

Photo 2. A NASA staff member interacts with attendees at the in-person Learning Area. **Photo credit:** NASA

Agriculture Data (Virtual)

This room focused on NASA data that are being applied to agricultural applications. The "How to Use NASA Data" button directed users to three subbuttons: the "Introduction to Data" and "Online Training" buttons linked participants to information on the NASA Applied Sciences Division's **Applied Remote Sensing Training** (ARSET) program, which offers online and in-person training in the use of NASA data for beginners and more seasoned practitioners alike. The third subbutton linked to a YouTube presentation by **Jim Acker** [GSFC, Goddard Earth Sciences Data and Information Services Center (GES DISC)] entitled **"Using Giovanni and NASA Data for Agricultural Insights."**[4]

The other three buttons in this section connected with several Data Pathfinders—commonly used datasets and associated tools across NASA's Earth science data collections—related to agricultural applications including Agriculture and Water, Disasters, and Water Quality. There are many more that can be found at the **Data Pathfinders site**.

Get Involved (Virtual)

This room had an educational focus, with links to various ways to get more connected and involved with NASA. Buttons included: Internships & Fellowships, Citizen Science, and Applied Sciences, and had links to the various NASA social media channels.

The agency is dedicated to developing applications that put the data and scientific findings to work for agricultural producers.

Conclusion

As was the case in 2022, NASA had a major presence at the Commodity Classic event. The variety and depth of the content provided just a sample of the practical support NASA offers an agricultural audience. The hybrid meeting format continues to be a success, with both the in-person and virtual exhibits being well attended.

All NASA data are open to the public and freely available, as was evident at Commodity Classic 2023. The agency is dedicated to developing applications that put the data and scientific findings to work for agricultural producers. The responses from attendees demonstrate that this focus on agricultural data is highly popular, and significantly contributes to building a more sustainable, resourceful agricultural industry. ■

[4] Giovanni is an application that is used to visualize selected geophysical parameters; it is straightforward to use and has become a multidisciplinary research tool.

Summary of the SAGE III/ISS Science Team Meeting

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Introduction

The Stratospheric Aerosol and Gas Experiment (SAGE) III on the International Space Station (ISS) [hereinafter written as SAGE III/ISS] science team meeting (STM) was held October 13–14, 2022, at NASA's Langley Research Center (LaRC) in Hampton, VA. **Jun Wang** [University of Iowa—*SAGE III/ISS Science Team Lead*], **David Flittner** [LaRC—*SAGE III/ISS Project Scientist*], and **Richard Eckman** [NASA Headquarters (HQ)—*Program Scientist*] convened the meeting, with approximately 60 scientists and engineers participating—either in person or remotely. They discussed the status of the mission, instrument operations, and data processing, and reviewed the latest scientific findings from studies that used the various SAGE III data products of ozone (O_3), aerosol, water vapor (H_2O), nitrogen dioxide (NO_2), and nitrogen trioxide, or nitrate (NO_3).

Since this is the first time since 2015 that *The Earth Observer* has reported on the SAGE III/ISS mission in detail,[1] this article begins with a brief overview of the mission to place the meeting in context, and then summarizes the meeting. Presentations can be found on the ***Science Team tab*** on the SAGE III/ISS website.

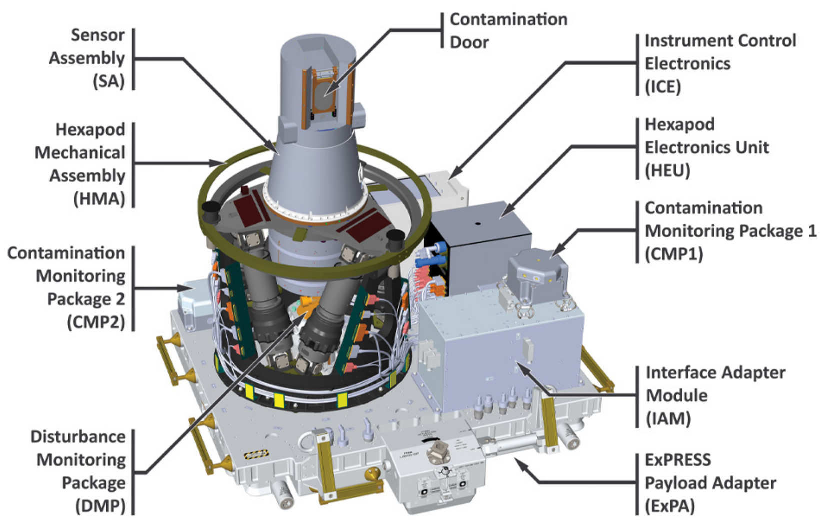

Figure 1. This graphic illustrates the components that make up the SAGE III/ISS payload. **Figure credit:** Institute of Environmental Sciences and Technology (IEST)/NASA

SAGE III/ISS Mission Overview

SAGE is a series of instruments designed by NASA to observe stratospheric O_3, aerosols, and H_2O from space. SAGE III—shown in **Figure 1**—is the newest and most advanced addition to the SAGE family.

Over the past four decades, the SAGE family of instruments has been critical in making accurate measurements of O_3 loss in Earth's atmosphere. The data collected from SAGE II helped political leaders around the world institute an international treaty banning products containing harmful chemicals that destroy stratospheric O_3. Indeed, the SAGE family has played a key role in measuring the onset of O^3 recovery resulting from the internationally mandated 1987 Montreal Protocol regulations.

Today, the SAGE *occultation* technique[2]—see **Figure 2** on page 12—is still the best for the job. NASA scientists sent the third generation of the instrument into space on February 19, 2017. Unlike the first two SAGE missions, which flew on unmanned satellites, SAGE III is mounted on the ISS where it operates concurrently with experiments from all over the world in and on the space-based laboratory. It was robotically installed on the outside of the ISS and is now taking important measurements of stratospheric gases and aerosols. Over the course of approximately one month, SAGE III measurements cover 70% of the planet.

Key Science Results from SAGE III/ISS to Date

The SAGE III/ISS mission is providing data necessary to assess the recovery in O_3 distribution, extend the aerosol record needed by both climate models and O_3 models, and gain further insight into key processes contributing to O_3 and aerosol variability. The ISS inclined orbit of 51.6° is a great match for SAGE III's solar occultation technique, yielding coverage to approximately ± 70° of latitude over the course of a year.

[1] To learn more about the history of the SAGE missions, as well as more background on the SAGE III/ISS mission, see **SAGE III on ISS: Continuing the Data Record** in the November–December 2015 issue of *The Earth Observer* [**Volume 27**, **Issue 6**, pp. 4–11].

[2] To learn more about the SAGE occultation technique, including a Figure illustrating the process, see page 5 of the article referenced in footnote 1.

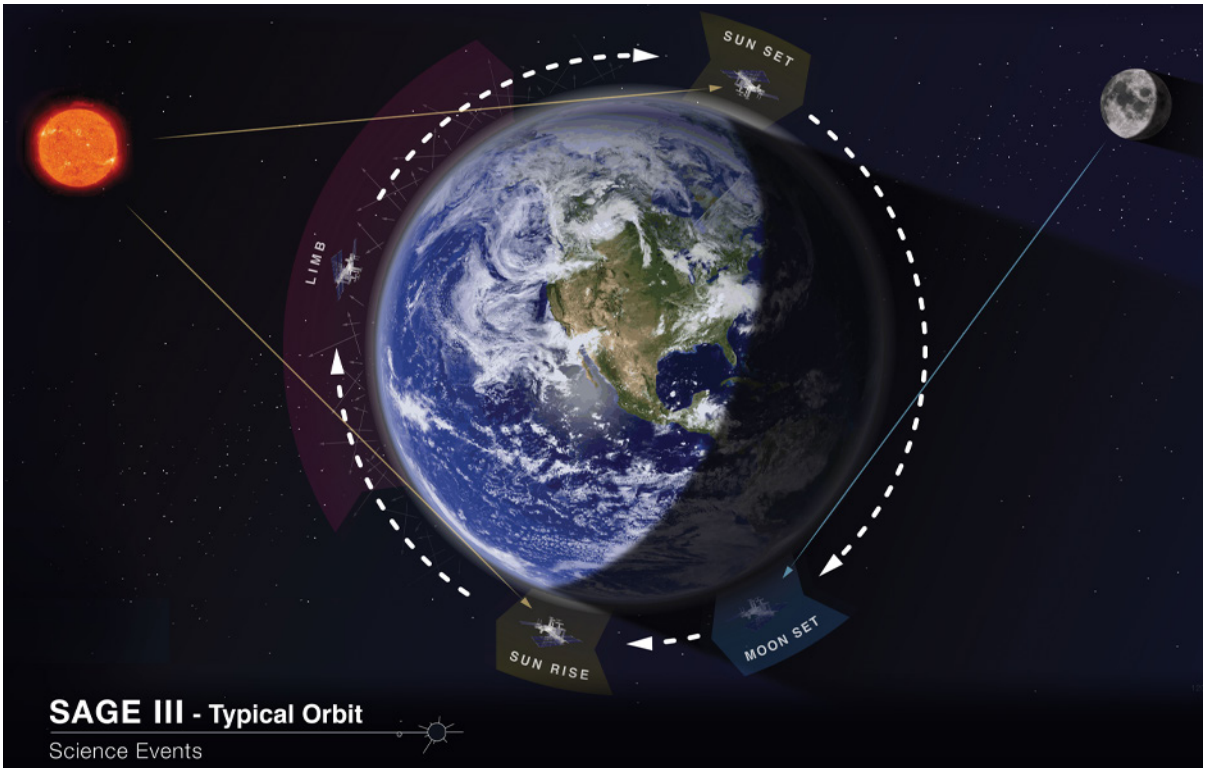

Figure 2. The SAGE III instrument takes measurements around the globe using a technique called occultation. Every time the Sun or Moon rises and sets (which, on ISS, occurs 15–16 times each day), SAGE uses the light that passes through the atmosphere to measure gases and particles in that region of the atmosphere. **Figure credit:** NASA

Mature SAGE III/ISS data products are yielding key findings—e.g., see **Figure 3**, below—that allow scientists to quantify recent changes in stratospheric O_3 (outside the polar regions) using a multi-instrument record that reaches back 38 years, and incorporates past and present SAGE data along with that of Canada's Optical Spectrograph and InfraRed Imaging System (OSIRIS) on Sweden's Odin satellite. Figure 3 shows that upper stratospheric O_3 has increased significantly since 2000—although the recovery shows an unexpected pause in the Northern Hemisphere. Combined with the likely decrease in O_3 in the lower stratosphere, this presents an interesting challenge in predicting the future of the O_3 layer.

SAGE III/ISS measurements helped to document the impact of the historically large injection of smoke into the stratosphere by the Australian bushfires of 2019 and

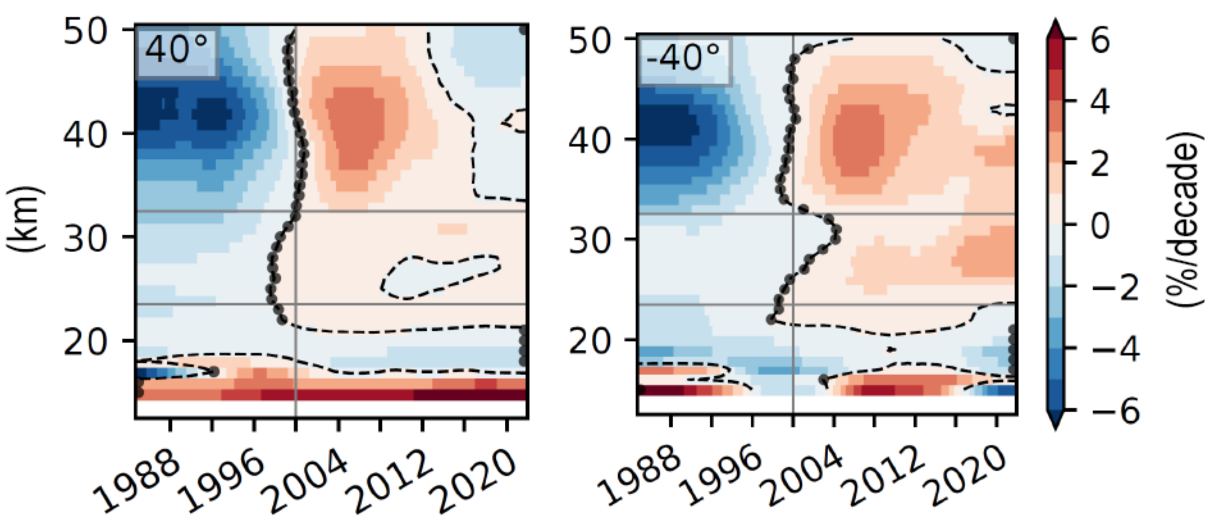

Figure 3. Hovmöller diagrams show ozone trends in percent per decade for two representative latitudes: 40º N and 40º S. The dashed lines show the zero-trend contours, and the dots indicate the minima of the trend. The horizontal lines delineate the stratospheric regions: lower, middle, and upper. **Figure credit:** Kristof Bognar/University of Saskatchewan, Institute of Space and Atmospheric Studies—from a **2022 paper published in Journal of Atmospheric Chemistry and Physics**.

Photo. In this photo captured from the ISS in March 2022 the Earth's limb is shown with a dark thin layer sitting in the bluish color of the stratosphere. This dark thin layer, between the blue and orange layers, is the remnant of the Tonga volcanic plume, lingering in Earth's stratosphere two months after the eruption that occurred in January 2022. **Photo credit:** Earth Science and Remote Sensing Unit, NASA's Johnson Space Center; Photo number: **ISS066-E-161686**; National Institute of Aerospace/NASA's Langley Research Center

2020. These observations demonstrated that important chemistry can occur on the smoke particle surfaces. In turn, this contributes to midlatitude O_3 depletion. Further laboratory studies are needed to extend scientific understanding of the surface chemistry.

More recently, SAGE III continues to observe changes in upper atmosphere chemistry and energy budget resulting from the spectacular eruption of Hunga Tonga–Hunga Ha'apai (HTHH) in January 2022—see **Photo**, above—which shows the remnants of the HTHH plume. From the standpoint of increased stratospheric aerosol, the event is viewed as a moderate eruption. However, SAGE observed unprecedented injection heights above 40 km (~25 mi)—which is beyond what SAGE II saw for Mt. Pinatubo (the largest volcanic eruption in the last 100 years which occurred June 15, 1991 in the Philippines)—and stratospheric column water vapor amounts 50-70% larger than consistently detected by *any* SAGE observation extending back to 1984. This substantial increase of a greenhouse gas is an atypical twist for volcanic eruptions in the satellite era. Initially, the enhanced aerosol and water vapor layers were confined to the Southern Hemisphere, but in recent months both have spread into the Northern subtropics, also rising within the tropical pipe. Though atmospheric impacts of HTHH are still unfolding, this event will serve as an excellent litmus test for climate models.

DAY ONE

The first day of the SAGE III/ISS STM consisted of opening presentations in which speakers gave programmatic and mission updates related to the SAGE III/ISS mission, followed by presentations relating to calibration and validation activities, as well as science results presentations to round out the day.

Opening Presentations/Mission Updates

David Flittner [LaRC—*SAGE III/ISS Project Scientist*] welcomed meeting participants. He reported that in July 2022, the mission logged five years of science operations. Flittner also said that ISS partners recently extended agreements for operations of ISS through 2030, with a flight manifest showing SAGE III as the only external payload occupying its current location on the Express Logistics Carrier (ELC)-4 during that timeframe. Pending successful navigation of the next *Earth Science Senior Review*—the regular Earth Science Division Review of Operating Missions—in 2023, SAGE III/ISS could potentially continue to deliver spectacular science products throughout this decade.[3]

Jamie Nehrir [LaRC—*SAGE III/ISS Mission Operations Manager*] reported on SAGE III mission operations over the past year. With over 50,000 solar occultations successfully acquired since science operations began in July 2017, the payload is operating nominally, with no

[3] **UPDATE:** As of this writing, SAGE III/ISS has submitted its Senior Review proposal along with other missions undergoing review during this cycle.

noticeable degradation impacting science performance. In July 2022—after significant delays—the Russian *Nauka* ("science" in Russian) module also known as Pirs ("pier" in Russian) docking module, which had been in place since 2001. When the SAGE III/ISS payload was designed, scientists and engineers assumed the MLM would already be deployed by the time the mission launched to ISS. The result of the delay in MLM's deployment was that, for the first five years of the mission, the ISS orientation has been near the edge of the SAGE III/ISS pointing system envelope. Notwithstanding these challenges imposed by ISS hardware delays, Nehrir reported that there have been no significant changes in the frequency of SAGE III/ISS occultation field-of-view blockages caused by ISS configuration changes and docked vehicles. With MLM now installed, SAGE III/ISS has finally assumed the configuration for which it was originally designed—and scientists eagerly anticipate being able to collect more science data over the nominal range of ISS attitudes.

Robbie Manion [LaRC—*SAGE III/ISS Science Computing Facility Lead*] introduced the personnel and hardware in the SAGE Science Computing Facility (SCF), which maintains, develops, and operates the algorithms for processing SAGE III observations into Level-1 data product (L1; atmospheric profiles of spectral transmission) and L2 (vertical profiles of aerosol and trace gases). Manion mentioned that the current operational processing output, Version 5.21 (v5.21), had released over 46,000 solar occultation events at that time and highlighted several perturbations to the stratosphere recorded in the SAGE aerosol products, as seen in **Figure 4**, below.

Manion also outlined attributes of the next version of data products (**v5.3 released in April 2023**): improved results for the 5% of events impacted strongly by mechanical disturbances, utilizes better vertical resolution and higher extent of the ancillary meteorological inputs, and includes more data from events occurring after the HTHH eruption due to revised quality assessment.

Charles Hill [LaRC—*SAGE III/ISS Deputy Project Scientist*] gave a presentation on the utilization of the Disturbance Monitoring Package (DMP) in data products. DMP is a subsystem of the SAGE III payload that was integrated to quantify mechanical disturbances. The DMP is comprised of a three-axis ring laser gyroscope Miniature Inertial Measurement Unit (MIMU) built by Honeywell Aerospace in Clearwater, FL. By calibrating coordinate transformations in orbit and using attitude-determination algorithms and an appropriate mechanical transfer function, the vibration-induced scan head boresight pointing anomaly is measured and will be used for postprocessing of the science product. Essentially, the DMP enables the correction of the SAGE III instrument boresight for vibration loading from ISS. Version 5.3 of the SAGE III/ISS data product includes the results of the DMP disturbance correction.

The considerable improvement in transmission profiles is evident in the L1B product for the most disturbed

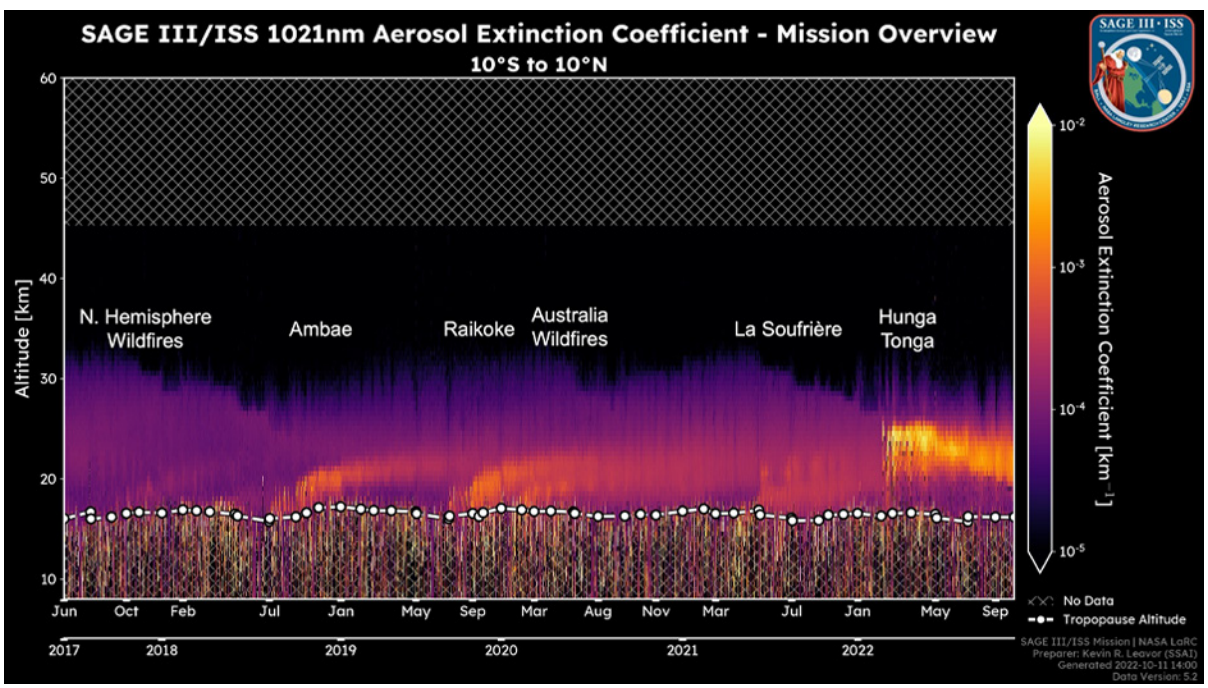

Figure 4. SAGE III/ISS vertically resolved aerosol extinction coefficient for the tropics over the current mission duration. Brighter colors denote larger extinction values, or a greater amount of aerosol particles in the measured region. Also plotted as circles are the daily average tropopause altitudes showing the invisible boundary between the troposphere below and the stratosphere above. Significant volcanic eruptions and extreme wildfires that have made a resulting mark on the stratosphere are annotated. **Figure credit:** NASA/Science Systems and Applications, Inc.

events. In general, the transmission uncertainties are improved for the entire data record. Effects on the L2 abundances are small owing to altitude binning of transmissions prior to inversion. However, the L2 uncertainties are generally reduced for the entire data record, and in particular are reduced an order of magnitude or more for the approximately 10% of science events that exhibited the greatest mechanical disturbances.

The SAGE III internal science team will release a paper soon with details of the disturbance corrections and their effects on the data product v5.3. Going forward, a Kalman-filtered absolute attitude correction to the limb-scattering experimental retrievals will be considered.

Jack Kaye [NASA HQ—*Associate Director for Research in the Earth Science Division*] gave a general introduction of NASA Earth Science research, shared the timeline of several recently launched and upcoming satellite missions—and reminisced about his early-career involvement with SAGE. He thanked the SAGE III mission operations team and expressed support for the SAGE III science endeavors, including those by both science team members and the overall science community.

Synergy and Calibration/Validation

Paul Newman [NASA's Goddard Space Flight Center (GSFC)] summarized the Asian Summer Monsoon Chemical and Climate Impacts Project (ACCLIP), which was flown in August 2022 from Osan Air Base in South Korea using the NASA WB-57f high-altitude research aircraft (15 local flights) and the National Science Foundation's (NSF) Gulfstream V jet (12 local flights) aircraft, along with extensive balloon observations. ACCLIP performed extensive sampling of the eastern flank of the Asian Summer Moonsoon Anticyclone (ASMA)—an anticyclonic circulation in the upper atmosphere—mapping the vertical and horizontal structure in the upper troposphere/lower stratosphere (UTLS). The researchers also sampled a number of ozone, particle, and water vapor sondes along the eastern flank of the ASMA. ACCLIP also measured the vertical and horizontal structure of ASMA shedding events into the Western Pacific, along with sampling of Super Typhoon Hinnamnor—partially characterizing the upper side of the typhoon and its outflow.

Peter Bernath [Old Dominion University] presented information on the Atmospheric Chemistry Experiment–Fourier Transform Spectrometer (ACE-FTS) and how it uses solar occultation to measure infrared atmospheric transmittance spectra from orbit. The gas phase molecular features can be removed to create *residual spectra* of aerosols and clouds. Analysis of the infrared spectra of stratospheric sulfate aerosol provides reliable information about composition (percent by weight of sulfuric acid), but deriving physical properties such as the size distribution requires optical data such as those from the SAGE III instrument. Preliminary analysis of coincident ACE-FTS and SAGE III observations allows complete characterization of stratospheric sulfate aerosols, assuming a single log-normal size distribution.

Thomas Pongetti [NASA/Jet Propulsion Laboratory (JPL)] reported on ground-based diurnal measurements of NO_2 and NO_3 to support SAGE III validation. JPL's Table Mountain Facility (TMF), has been measuring the 24-hour diurnal cycle of NO_2 and NO_3 using solar, lunar, and sky light. The TMF team compared their ground-based observations to a zonal subset of the SAGE III findings in the latitude band surrounding TMF. Pongetti presented the methodology and evaluation of these results, showing excellent agreement for stratospheric NO_2, including the L2 lunar product—still in research status. Continued work will quantify the differences of the tropospheric contributions between the space- and ground-based occultations.

Lars Kalnajs [University of Colorado Boulder, Laboratory for Atmospheric and Space Physics (LASP)] gave a presentation on LASP's stratospheric ballooning program and how it has continued to make coordinated *in situ* measurements from Boulder, CO, of stratospheric aerosol size distribution using the LASP Optical Particle Counter. This validates the SAGE III aerosol extinction products and continues a 55-year record of stratospheric aerosol. These profiles continue to show a perturbed and highly variable midlatitude stratospheric aerosol layer, attributable to a series of medium-sized volcanic eruptions and large wildfire events. SAGE III aerosol extinction is generally in good agreement with extinction derived from the *in situ* size distributions. On a profile-by-profile basis from the tropopause to approximately 26 km (~16 mi), aerosol extinction coefficients at 521, 755, and 1022 nm agree to within instrument uncertainty. There is an indication of a low bias in the 1022-nm aerosol extinction relative to the *in situ* measurements—although still within uncertainty. Above 26 km the agreement between SAGE III and the *in situ* data is less robust, with satellite-derived extinction falling slightly below the *in situ* data. As part of the ACCLIP project, researchers performed additional balloon-based aerosol soundings during the Asian Summer Monsoon (ASM) season in Korea. However, comparisons of these data to SAGE III data were inconclusive due to the increased spatial and temporal variability associated with the Asian Tropopause Aerosol Layer (ATAL). Ongoing work uses spectral data in the SAGE III aerosol extinction channels to identify ASM/ATAL aerosols near the tropopause based on their distinctive size distributions and Angstrom exponent.

Science Results and Data Quality

Following the programmatic and calibration/validation presentations, the remainder of the meeting was devoted to presentations on science being achieved using SAGE III/ISS and other data. Topics encompassed atmospheric constituents, including ozone, trace gases, aerosols, and synergistic combinations of these and new data findings resulting from the team's endeavors.

Ozone Science and Network

Anne Thompson [University of Maryland, Baltimore County (UMBC), Goddard Earth Sciences Technology and Research II (GESTAR II)] described the stability of the global ozonesonde network. Ozonesonde profile measurements are popular with the SAGE III Science Team as input in developing stratospheric O_3 algorithms and evaluating O_3 data products. Sonde data are also used as a reference when O_3 products from a suite of operational satellites are compared. These applications require O_3 data of ~5% uncertainty or better. Since 2016 the World Meteorological Organization's (WMO) Assessment of Standard Operating Procedures for Ozonesondes (ASOPOS) 2.0 activity has been evaluating updated ozonesonde profile archives, e.g., from Network for the Detection of Atmospheric Composition Change (NDACC)[4] and GSFC's Southern Hemisphere ADditional OZonesodes (SHADOZ),[5] as well as results of laboratory and field tests of ozonesonde instrumentation. Thompson described the development of an ASOPOS 2.0 WMO/Global Atmospheric Watch (GAW) Programme's publication (**Report 268**) outlining consensus-based ozonesonde "best practices" for operations and data processing. A byproduct of ASOPOS 2.0 was an evaluation of the quality of total and stratospheric O_3 columns using the Ozone Monitoring Instrument (OMI) and Microwave Limb Sounder (MLS) on NASA's Aura platform and ~40,000 soundings from the 60-station global network. From 2005–2021 the total column O_3 from the sondes displays a mean deviation from satellite (or ground-based) spectrometers of 2% or less. This achievement is a game-changer for ozonesonde data quality. First, SAGE III/ISS users can be confident of the sonde data. Second, through ongoing evaluation and updates of the global ozonesonde record by the ASOPOS 2.0 process, the satellite community can look toward even better precision in O_3 profiles in the near future.

Ryan Stauffer [GSFC] gave a presentation titled *"Ticosonde: 17 years of balloon-borne Ozone and water vapor profiles in Costa Rica,"* which summarized O_3 and H_2O sonde data collection and comparisons with SAGE III and Aura MLS since the joint NASA/NOAA/Costa Rica Ticosonde Balloon Sounding Project began in 2005. Ticosonde is the only long-term, tropical, *in situ*, water-vapor sonde dataset in existence, making it vital in validating SAGE III measurements. H_2O sonde agreement with SAGE III is within 5% in the stratosphere—underscoring the quality of both balloon and SAGE III observations. The Ticosonde measurements also recently captured stratospheric H_2O from the 2022 HTHH volcanic eruption, showing enhancements of two-to-three times the normal values. Ticosonde and SAGE III observations will be essential for monitoring the evolution of enhanced stratospheric H_2O and determining its impact on our climate.

Irina Petropavlovskikh [NOAA] presented a comparison of O_3 vertical profiles from SAGE III and ground-based Umkehr[6]-effect O_3 profiles made by NOAA in Boulder, CO. In addition, her team compared the Umkehr-effect profiles to ozonesondes and Aura MLS observations and found that SAGE III v5.2 O_3 was both comparable to the earlier version and stable with respect to ground-based observations. Petropavlovskikh emphasized the importance of high-resolution O_3, aerosol, and H_2O altitude measurements in the UTLS to track changes in atmospheric composition, particularly with Aura MLS observations coming to an end within the next few years. The second phase of the World Climate Research Programme's (WCRP) Stratospheric-tropospheric Processes and their Role in Climate (SPARC) Long-term Ozone Trends and Uncertainties in the Stratosphere (LOTUS) initiative continues to use SAGE observations in its merged satellite O_3 records. She concluded that the continuation of the SAGE III record is important for verifying the combined satellite records and trend analyses, and that the consistency between ground-based and satellite records is important for monitoring O_3 recovery.

DAY TWO

Most of the second day of the meeting was a continuation of the science results presentations that began on the first day. There was also a concluding session to close out the meeting.

[4] To learn more, see **The Network for the Detection of Atmospheric Composition Change: 25 Years Old and Going Strong** in the September–October 2016 issue of *The Earth Observer* [**Volume 28**, **Issue 5**, pp. 4–15].

[5] To learn more, see **SHADOZ at 20 Years: Achievements of a Strategic Ozonesonde Network** in the September–October 2019 issue of *The Earth Observer* [**Volume 31**, **Issue 5**, pp. 4–15].

[6] *Umkehr* is the German word for "reversal." It is a measure of the time variation of the ratio of the scattered intensity at two different wavelengths. The *Umkehr effect* is observed when measurements are made with an utlraviolet spectrophotometer of the ratio of the zenith sky light sky light intensities of two wavelengths in the solar ultraviolet when the Sun is near the horizon.

Science Results (*cont'd*)

Trace Gases

Emma Knowland [GSFC/Morgan State University] gave a presentation on the NASA Goddard Earth Observing System (GEOS) Earth system model and its new capability to assimilate multiple constituents from ground- and space-based instruments using the GEOS Constituent Data Assimilation System (CoDAS). The recently released Modern-Era Retrospective analysis for Research and Applications-2 (MERRA-2) Stratospheric Composition Reanalysis with Aura MLS (M2-SCREAM) assimilates v4.2 MLS O_3, H_2O, and other chemically reactive species with the NASA GEOS model coupled to a stratosphere-only chemistry mechanism and transport constrained to the MERRA-2 reanalysis. While the number of solar occultation observations per day from SAGE III is about 1% of the total number of profiles observed globally by MLS, the chemical timescales of O_3 and H_2O in the lower stratosphere are long enough that the SAGE III data may provide a useful constraint on the assimilated product. Using the same GEOS CoDAS configuration as M2-SCREAM, Knowland and her team conducted a series of experiments to investigate the consistency of H_2O trends with the assimilation of SAGE observations, both with and without Aura retrievals. This helps to determine if the assimilation of SAGE observations produces a steady product for trend analysis, especially as the end of the Aura mission nears.

Knowland concluded that assimilating only SAGE III H_2O profiles results in H_2O fields more consistent with experiments that assimilate MLS v5. However, in the Polar Regions SAGE III observations are not available and the values are unconstrained. She and her team are encouraged by the benefit that assimilating the less-frequent SAGE III observations has on stratospheric composition. Sensitivity experiments such as these will allow the team to assess the added value of SAGE data for continued monitoring of the stratospheric composition for climate and O_3 recovery assessments.

Melody Avery [NOAA] gave a presentation titled *"Determining Tropical Width and Tropical Tropopause Layer (TTL) Boundaries Using Trace Gas, Cloud and Aerosol Observations."* Avery's team seeks to develop a new metric for determining the width of the tropical Hadley cell using high-vertical-resolution cloud and aerosol observations from SAGE III and the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation's (CALIPSO) Cloud Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument. The team used a simple cloud-aerosol discrimination method for sorting the SAGE III data to allow them to compare SAGE III and CALIPSO seasonal zonal mean cloud distributions from June 2017–January 2022 at altitudes from 12–20 km (~7–12 mi). The comparison showed that the boundaries of cloudiness detected by SAGE III and CALIOP agree very well, both horizontally and at the tropopause. As expected, these correspond to sharp gradients in SAGE III water vapor data. Pronounced hemispheric and zonal asymmetries related to the boreal summertime Asian Monsoon observed by both SAGE III and CALIOP show cloud tops extending higher than 18 km (~11 mi), with the tropopause break at 35 °N. Future research using SAGE III and CALIOP cloud and aerosol data will include defining the tropical width in meridional sections, as opposed to defining the tropical width by using the seasonal zonal mean.

Kristof Bognar [University of Saskatchewan, *Canada*] presented information on stratospheric O_3 trends in the SAGE II, OSIRIS, and SAGE III data sets. Bognar and his team quantified recent changes in stratospheric O_3 (outside the polar regions) using a combination of the three satellite datasets. They found that upper stratospheric O_3 has increased significantly since 2000—although the recovery shows an unexpected pause in the Northern Hemisphere. Combined with the likely decrease in O_3 in the lower stratosphere, this presents an interesting challenge for predicting the future of the O_3 layer.

Aerosols

Travis Knepp [LaRC] presented information from past research groups that have used SAGE extinction spectra to estimate particle size distribution (PSD) parameters (e.g., mode radius and distribution width). Most of these studies failed to account for measurement error; no study, to date, has used a bimodal distribution in their solution space. Knepp's project will find PSD solutions that include measurement error and will provide confidence levels for all PSD solutions. Further, Knepp and his team will expand the analysis to include a bimodal solution space. Knepp presented overall algorithm processing and presented preliminary results that demonstrate how sensitive the PSD estimates are to the model's assumptions (e.g., refractive index).

Xi Chen [University of Iowa] reported on the impact of pyrocumulonimbus (pyroCbs) clouds on UTLS atmospheric composition. Based on the stratospheric aerosol mass estimation for the 2019–2020 Australian wildfires event using the "top-down" method from satellite observations, Chen's team developed a three-dimensional pyroCb emission inventory including smoke aerosols and carbon monoxide (CO), taking into account injection height into the UTLS. Implementing this pyroCb emission into GEOS–Chem, a chemical transport model, the team compared the simulated aerosols and CO evolution with SAGE III and overall data from the two sources aligned well—except for slightly lower aerosol extinction values at higher altitudes. Consideration of the injection height of pyroCb emission in UTLS can lead an approximately four-fold increase in radiative forcing from smoke particles and result in significant warming in the UTLS. Futher work will focus on quantifying the impact of aerosols from pyroCb events on the evolution of ozone profiles through heterogeneous reactions.

Fangqun Yu [State University of New York at Albany] discussed stratospheric aerosol size distributions and optical depth. A size-resolved (sectional) advanced particle microphysics model (APM) has been integrated with the GEOS-Chem tropospheric–stratospheric unified chemistry extension (UCX) and the resulting GEOS-Chem-UCX/APM model has been used to study the evolution of particle size distributions in the stratosphere. Yu reported that nucleation schemes have a strong effect on the model-simulated particle number concentration and size distribution in the stratosphere. The *in situ* measurements indicate a bimodal structure of accumulation mode particles both in the stratospheric background and in the volcano-perturbed stratosphere, which is not captured by the present model; the possible reasons remain to be studied. The effect of charges on coagulation and growth of particles in the stratosphere may be one reason. Comparisons of long-term simulated stratospheric aerosol optical depth (SAOD) with Global Space-based Stratospheric Aerosol Climatology (GloSSAC) data (in which SAGE III is a major contributor) and balloon data show that the model generally captures the observed variations but indicates some differences, which remain to be further investigated. The model simulations also indicate that the Asian tropopause aerosol layer (ATAL) associated with the Asian summer monsoon anticyclone appears to be a significant source of stratospheric particles.

Synergy and New Products

Michael Pitts [LaRC] provided an update on the status of the SAGE III Temperature and Pressure research product. Temperature and pressure profiles are retrieved from multispectral measurements across the oxygen A-band absorption feature near 762 nm. The retrievals are highly sensitive to forward-model parameters such as wavelength registration and instrument response. Implementing derived adjustments to baseline estimates of these parameters leads to significantly improved retrieved temperature and pressure profile products. Further refinements to the forward model are being considered and more comprehensive correlative comparison studies are planned for the near future.

Mahesh Kovilakam [LaRC] discussed a new cloud-free aerosol data product for SAGE III. Kovilakam and colleagues presented information on the implementation of a cloud-screening algorithm for an L3 product consisting of flags for a range of aerosol-only conditions and aerosol/cloud mixtures and polar stratospheric clouds. These data have already been incorporated into the latest GloSSAC v2.2. Differences between GloSSAC v2.0 and this new version are attributable to version differences of individual datasets, and improved cloud screening of SAGE III data. This L3 product will be produced in concert with the regular SAGE III L1 and L2 data products soon after v5.3 is operational and released.

Danny Mangosing [LaRC] provided a demonstration of a new web page that will help complement validation and analysis of SAGE III data. A new **Quicklook static imagery webpage** depicting the SAGE III aerosol extinction coefficient, aerosol-to-molecular extinction ratio, and NO_2, O_3, and H_2O in the form of mission summary, monthly zonal means, weekly curtain, and daily profile plots has been deployed on the SAGE III project website.

Conclusion

The SAGE III/ISS STM was successful and provided a welcome opportunity for the mission and science teams to collaborate after two years of completely virtual science team meetings—the latter being a common refrain at many recent STMs. Attendees had the opportunity to learn about the status of the SAGE III/ISS instrument, recently released data products, and the science research and results being achieved by the mission and science team members.

On behalf of the SAGE III/ISS Science Team, at the end of the meeting **Jun Wang**, SAGE III/ISS Science Team Lead, thanked LaRC for helping host and coordinate the logistics of the meeting. He noted that with the increase in large fires and volcanic eruptions in the past 5–10 years, the need for SAGE III measurements and data is critical to help scientists understand how the atmospheric composition in the UTLS is changing. He and many science team members also acknowledged the excellent work that the mission operations team had done in the past several years (and in particular during the COVID-19 pandemic) keeping the SAGE III instrument functioning normally and continuing to provide the science community with timely and high-quality scientific data.

The next STM is planned for the fall of 2023. With the ISS operations agreement newly renewed to 2030, the SAGE III mission has the potential to extend observations through this decade, engaging the science community via vital data records and more stimulating STMs. ■

Summary of the 2022 Ocean Surface Topography Science Team Meeting

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Introduction

The 2022 Ocean Surface Topography (OST) Science Team Meeting (STM) was held in Venice, Italy, October 31–November 4, 2022. This year's meeting lasted four and a half days and included special sessions on the history of European–U.S. cooperation on altimetry, chaired by OST Science Team (OST ST) project scientists, and splinter sessions on the Sentinel-6 Validation Team.

The primary objectives of the OST STM were to address specific technical issues on the reference altimetry missions,[1] including algorithm and model improvement, calibration/validation (cal/val) activities, merging the Ocean Topography Experiment (TOPEX)-Poseidon–Jason–Sentinel-6 Michael Freilich (S6MF) data with those from other altimetric satellites, and preparation for the **Surface Water and Ocean Topography** (SWOT) and other future OST missions.[2]

The meeting began with an opening plenary session, followed by science keynotes and a series of splinter sessions, and then a closing plenary session. The splinter session topics included sessions on a variety of algorithm improvements and measurement uncertainties, as well as sessions on coastal altimetry, the **Chinese–French Oceanography Satellite** (CFOSAT)[3] mission, and science topics ranging from climate and oceanography to hydrology and cryosphere science. The complete list of splinter sessions can be found on the **meeting website**.

This report begins with an overview of the status of current and planned OST missions, followed by a brief summary of the OST STM itself. For more details, readers can **download the full OST STM report**. The **full OST STM program** lists all of the presentations from the plenary, splinter, and poster sessions, and includes links to many of the presentations and to abstracts for the posters.

[1] This line of missions includes the Ocean Topography Experiment (TOPEX)–Poseidon (1992–2006), Jason-1 (2001–2013), Ocean Surface Topography Mission (OSTM)/Jason-2 (2008–2019), Jason-3 (2016–present), and Sentinel 6 Michael Freilich (S6MF; launched in 2020). It will also include Sentinel-6B (scheduled to launch in 2025).

[2] **UPDATE:** SWOT launched December 16, 2022; so as of this publication, it is a *current* mission—but at the time of the meeting it was still *future*.

[3] CFOSAT successfully launched on October 29, 2018, at 12:30 AM UTC aboard a Chinese Long March 2C rocket from Jiuquan Satellite Center in China.

Status Report on Current Ocean Surface Topography Missions

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

Sentinel-6 Michael Freilich

The S6MF mission launched on November 21, 2020, from Vandenberg Air Force Base (now Space Force Base) and successfully completed its commissioning and subsequent entry into routine operations on schedule, one year later. More recently S6MF succeeded Jason-3 as the *Reference Mission*—i.e., the mission that other altimetry missions are compared to—on April 7, 2022, at which point Jason-3 vacated the reference orbit. The first full mission reprocessing of products was released on July 28, 2022.

Jason-3

Jason-3 continues its extended mission and is fully operational with all redundant systems available. It completed a longer than initially planned 15-month tandem phase with S6MF, which allowed calibrating both the primary and redundant altimeters on S6MF. On April 25, 2022, Jason-3 began operations in an orbit that optimally interleaves ground tracks with S6MF to improve the overall temporal and spatial coverage provided by both missions.

Sentinel-3A and -3B

Sentinel-3A and -3B were launched in February 2016 and April 2018, respectively. Much like past missions in the reference orbit, a tandem phase with a separation of 30 seconds between the two satellites was performed to provide cross-calibration. Subsequently, Sentinel-3B was placed in a nominal orbit that is 140° out of phase with Sentinel-3A and both missions now provide sea level measurements along high-inclination tracks as part of routine operations. Full-mission reprocessing of land altimetry Level-2 (L2) products will be completed in 2023.

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

Turning toward the future, Sentinel-6B, the successor to S6MF, has been completed and is now in storage awaiting launch in 2025. Identical to S6MF, it will assure operational continuity through the end of 2030. An additional satellite, Sentinel-6C, is under consideration by the agencies, which would extend observations through 2035.

Satellite with Argos and AltiKa (SARAL)[4]

SARAL is a French Space Agency (Centre National d'Études Spatiales (CNES)) satellite that carries a high-inclination K_a-band radar altimeter (AltiKa) and has been in a drifting orbit since launch in July 2016. Both SARAL and AltiKa continue to perform nominally after more than six years in orbit.

Discussion of Future Missions Relevant to OST

There were presentations on several other existing and upcoming missions in various stages of development, each with applications relevant to OST. Each presentation included information on the mission's status and development plans, as described below.

Surface Water Ocean Topography

The Surface Water Ocean Topography (SWOT) mission is a joint NASA–CNES mission scheduled to launch December 16, 2022. The primary instrument on SWOT is the K_a-band Radar Interferometer (KaRIN)—the first spaceborne, wide-swath, altimetry instrument capable of high-resolution measurements of *sea surface height*[5] in the ocean and freshwater bodies. After commissioning and initial calibration, beta products are expected to be available in mid-2023.[6]

Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL)

This is one of six high-priority candidate **Copernicus Sentinel Expansion Missions** that are being studied to address European Union needs, as well as to extend the current capabilities of the Copernicus space components. CRISTAL would carry a multifrequency radar altimeter and microwave radiometer to ensure the continuity of sea ice thickness measurements—with improved quality compared to its predecessor Cryosat-2—and—for the first time—measure overlying snow depth.

Recommendations from the OST Science Team

After discussing these missions and other issues concerning altimetry, the OST STM adopted the following three recommendations:

Second Jason-3/Sentinel-6 Michael Freilich Tandem Phase: Given the societal importance of the sea level record and the need to understand its long-term uncertainty, the OST ST recommends to the Jason-3 Project an additional tandem phase between Jason-3 and S6MF that lasts 12 cycles, after at least 2 years into the interleaved mission. The OST ST recognizes that the second tandem mission should have no operational impact on S6MF.

Sentinel-6B Commissioning: The OST ST recommends that during commissioning Sentinel-6B should: operate both sides of the altimeter; execute a *tandem mission* with S6MF of at least 10 cycles on both sides of the altimeter;[7] use each side of the instrument in different modes of data retrieval (low resolution, raw synthetic aperture radar (SAR), compressed SAR); and should include attitude flip maneuvers as performed for S6MF to improve orbit determination.

OneArgo: Recognizing the decline in the existing core **Argo** array and the need to strengthen the complementary observations between altimetry and Argo, including the need for closure of global and regional sea level budgets, quantifying Earth's energy imbalance, and understanding interaction of the biosphere and ocean physics, the OST ST supports the full deployment and sustainment of all three components of **OneArgo**, an integrated global, full depth, and multidisciplinary ocean observing array.

Opening Plenary Session Highlights

Pascal Bonnefond [CNES] began with welcoming remarks on behalf of all the project scientists, who (in addition to himself) include **Josh Willis** [NASA/Jet Propulsion Laboratory (JPL)], **Eric Leuliette** [National Oceanic and Atmospheric Administration (NOAA)], **Remko Scharroo** [European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)], and **Craig Donlon** [European Space Agency (ESA)]. In particular, Pascal noted the addition of **online forums**, available until the next OST STM, that can be accessed after logging in to the site. In addition, Willis announced the addition of a new OST ST Deputy Project Scientist, **Severine Fournier** [JPL], who is lead author of this summary.

[4] Argos is a French data-collection system; AltiKa is an acronym for a K_a-band altimeter. SARAL is a cooperative altimetry mission between the Indian Space Research Organisation (ISRO) and CNES.

[5] Sea surface height is an indicator of the amount of heat stored in the ocean. It is measured relative to a reference standard called the *geoid* and can be used to create a "topographic map" of the ocean.

[6] **UPDATE:** The NASA/CNES Surface Water and Ocean Topography (SWOT) Satellite successfully launched on December 16, 2022, with subsequent release of its first data in January 2023. See **"The Editor's Corner"** of the January–February 2023 issue of *The Earth Observer* [**Volume 35**, **Issue 1**, pp. 1–2] to view some of these images—which show the potential of the new mission above and beyond its predecessors.

[7] Like most satellite missions, Sentinel-6B will have redundant electronics for the altimeter instrument referred to as the *A-side* and *B-side*.

Program managers gave presentations on the status of altimetry and oceanographic programs at their respective institutions including: **Nadya Vinogradova-Shiffer** [NASA], **Annick Sylvestre-Baron** [CNES], **Estelle Obligis** [EUMETSAT], **Eric Leuliette**, and **Jérôme Benveniste** [ESA].

In addition, **François Bignalet-Cazalet** [CNES] gave a special presentation on climate change and the carbon footprint of the OST STM meeting itself. He provided an overview of human-caused climate change, detailed specific contributions to greenhouse gas emissions from individual actions, and asked what the OST STM can do to reduce its own carbon footprint.

Meeting Highlights

In addition to the splinter sessions, a special keynote science session took place after the plenary session. While space limitations preclude describing all the sessions in detail, complete coverage of the results can be found at the website mentioned in the Introduction. This report will focus on the science keynote session and one of the splinter sessions, which presented scientifically compelling results.

Science Keynotes

During the science keynotes, **Jonathan Chenal** [Laboratoire d'Études en Géophysique et Océanographie Spatiales (LEGOS)], a French research laboratory, gave a presentation on the Earth Energy Imbalance (EEI). The EEI refers to the difference between incoming and outgoing energy, averaged over the entire planet. Chenal noted that 93% of this extra heat is absorbed by the ocean, which is an important contribution to sea level rise. He explained that his imbalance can be separated into the forcing caused by greenhouse gases and aerosols and Earth's responses.

The researchers used a common technique to describe global warming, where they estimate the amount of warming expected from a doubling of atmospheric CO_2. They call this estimate the *equilibrium climate sensitivity* (λ,). Chenal showed that this value changes over time and could be related to the Pacific Decadal Oscillation (PDO) index—see **Figure 1**, *below*.

During another science keynote presentation, **Noël Gourmelen** [University of Edinburgh] presented his work on the interferometric swath radar altimetry for the study of the cryosphere. Satellite altimeter observations of ocean surface topography have always been challenging in the polar regions, where sea ice is present—sometimes year-round. However, the primary instrument on ESA's CryoSat-2 mission is the Synthetic Aperture Interferometric Radar Altimeter (SIRAL), which was designed to measure ice-sheet elevation and sea-ice freeboard. Thanks to its Synthetic Aperture Radar Interferometric (SARin) mode, there is an increase in coverage for land ice compared to the traditional Point Of Closest Approach (POCA) mode—see **Figure 2** on page 22. This allows CryoSat-2 to be extremely useful for many applications—e.g., estimation of ice-shelf thinning and melting, subglacial hydrology, and observing changes in mountain glaciers. In this way, CryoSat-2 helps to monitor *glacier mass*—an important contribution to sea level rise. The caveat is that, due to its inclination, CryoSat-2 is highly sensitive to satellite attitude—especially rolling. The upcoming SWOT and proposed CRISTAL missions will have design improvements that reduce these issues.

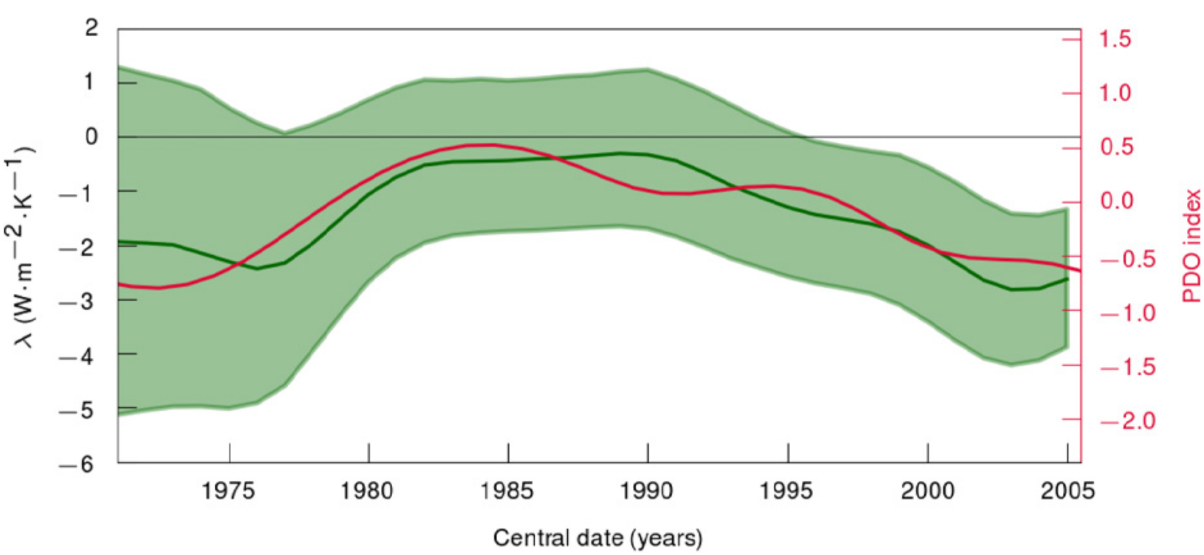

Figure 1. This graph shows the variations of the *equilibrium climate sensitivity* (λ)—which relates the Earth's radiative response to the global mean surface temperature—for periods over 25 years (green) and time series of the PDO index (red). This shows that the variations of λ are very well correlated with the PDO. **Image credit:** Jonathan Chenal/LEGOS

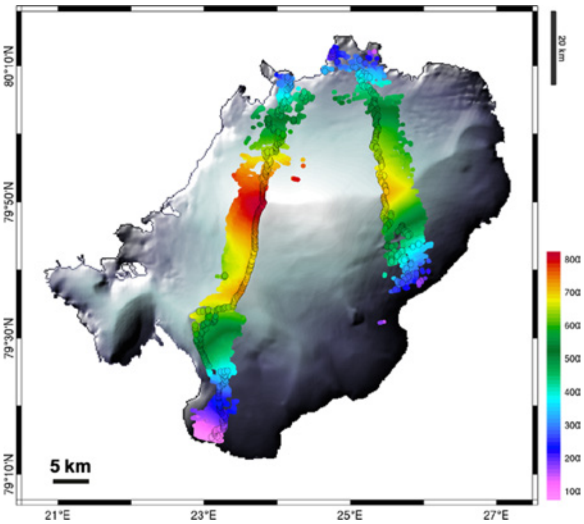

Figure 2. This map represents a scheme showing the spatial coverage of CryoSat-2 swath SARin mode compared to the Point Of Closest Approach (POCA) mode. There is an increase in CryoSat-2 coverage for land ice compared to the POCA mode. **Image credit:** Noël Gourmelen/University of Edinburgh

Application Development for Operations

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

Hurricanes are fueled from heat stored in the ocean, and can intensify over warmer water. **David Trossman** [Oregon State University] presented work on the Next Generation Enterprise (NGE) Ocean Heat Content (OHC) which uses machine learning to derive a sophisticated regression between a large historical database of temperature and salinity profiles with ocean topography from altimetry. This observation-based product gives a three-dimensional view of the global ocean which is useful for better hurricane predictions—see **Figure 3**, *below*. Because of the large database of observations

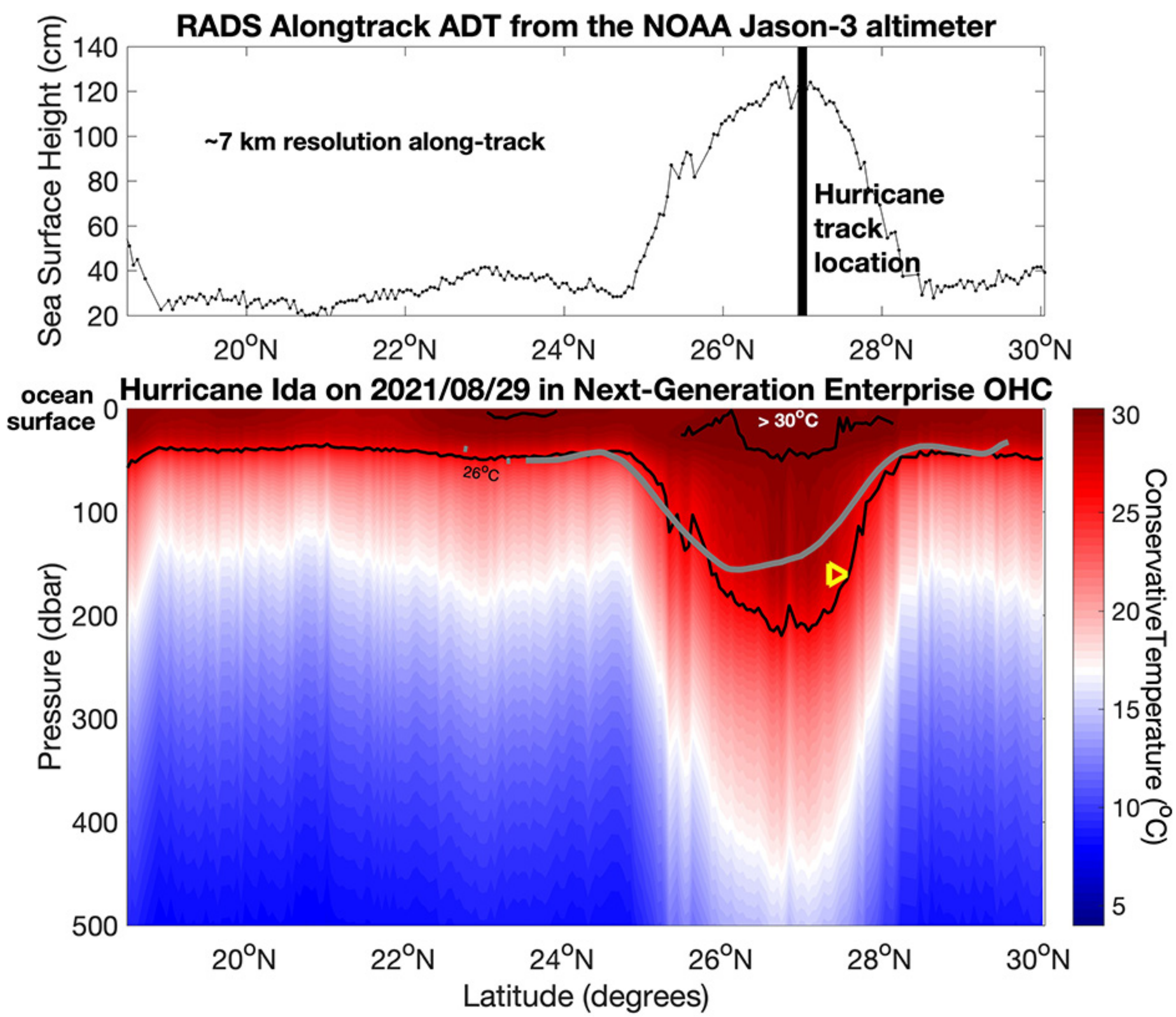

Figure 3. During Hurricane Ida the NGE OHC algorithm decreased the error in estimating the Argo-observed depth of the 26 °C (78.8 °F) isotherm from 31.5 m (~103 ft) for the legacy product to 3.25 m (~10.7 ft) for the NGE OHC algorithm. **Image credit:** David Trossman/Oregon State University

used—which includes altimetry observations—the model can accurately model a deep pool of warm water in the Gulf of Mexico. In the latest iterations, the methodology upgrades—in particular, the use of machine learning—led to a significant improvement when compared to earlier versions.

Closing Plenary Session Highlights

The closing plenary session included reports on each splinter session. In their remarks, the representatives of each topic area gave responses to comments on key discussion items posed by the project scientists at the beginning of the meeting.

Jean-Damien Desjonquères [JPL] gave an update on the reprocessing of TOPEX/Poseidon mission data. Several long-standing issues in the TOPEX/Poseidon data record (e.g., instabilities in the radar signal and insufficient calibration at the time) are finally being addressed and corrected. The reprocessed products have been fully generated and a user manual is in progress, with a release on to the Physical Oceanography Distributed Active Archive Center (PO.DAAC) and the Archiving, Validation and Interpretation of Satellite Oceanographic (Aviso+) data portal, targeted to occur during 2023.

Conclusion

During the closing session, the OST STM adopted the recommendations to have a second Jason-3/S6MF Tandem Phase in order to improve our understanding of the sea level record's long-term uncertainty, as well as to prioritize the support to the OneArgo *in situ* instrument network that is essential, along with altimetry, to close the global and regional sea level budgets, quantify Earth's energy imbalance, and understand interaction of the biosphere and ocean physics. The OST ST also adopted recommendations regarding the upcoming Sentinel-6B commissioning phase, as stated on page 19 of this article.

In addition, the OST STM expressed its strong support for the continuation of the SARAL/AltiKa drifting period for as long as possible, with its altimeter being the most important for future improvements in mean sea surface and gravity.

As has become customary for such gatherings, this OST STM ended with several acknowledgements and kudos, several of which refer to recommendations made by the OST STM. The team acknowledged the various space agencies for maintaining the launch schedule of Sentinel-6 to overlap with Jason-3, and their ongoing support of data-reprocessing efforts. Additional acknowledgements can be found in the full OST STM report link referenced in the Introduction.

The meeting fulfilled all its objectives. It provided a forum for updates on the status of Jason-3 and S6MF and other relevant missions and programs and for detailed analyses of mission observations by the splinter groups. The team concluded that data from the Jason-3 and S6MF altimeters continue to meet the accuracy and availability requirements of the science community.

The 2023 OST STM is scheduled for November 7–11, 2023, in San Juan, Puerto Rico. ■

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

A New Way to Explore Climate Data: NASA Opens the Earth Information Center

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

In a new interactive exhibit at the Mary W. Jackson NASA Headquarters building Headquarters (NASA HQ) in Washington, DC, visitors are invited to see Earth as NASA sees it from space. For six decades, NASA satellites, sensors, and scientists have collected data on Earth's land, water, air, and climate. At NASA's new Earth Information Center (EIC), the public can glimpse what this data has taught us about sea level rise, air quality, wildfires, greenhouse gases, ice cover, and agriculture.

The Earth Information Center is both a physical space and **a web-based experience** drawing on research conducted by teams at NASA's different centers, at academic institutions, and by industry partners. NASA is developing the EIC along with founding partners from the National Oceanic and Atmospheric Administration (NOAA), the U.S. Geological Survey (USGS), the U.S. Department of Agriculture (USDA), the U.S. Agency for International Development (USAID), the Environmental Protection Agency (EPA), and the Federal Emergency Management Agency (FEMA). The physical space is in the east lobby of NASA HQ—see **Photos 1** and **2**—and is open to visitors from 8:30 AM to 5:30 PM. Eastern Daylight Time Monday through Friday.

"Teamwork enabled the success of this project, which included contributions from just about every NASA center and six partners across the government," said **Laura Rogers** [NASA's Langley Research Center—*Associate Program Manager, Ecological Conservation*]. "We brought together very different perspectives—blending things like the view from space with the view from behind the wheel of a tractor—to make complex data and concepts more accessible through visuals and sound. The center is a powerful combination of space, science, Earth, and art."

Seeing Earth as NASA Sees It

As visitors enter the exhibit, they are greeted by chirping birds and other natural sounds. Once inside, they will find a 22-foot LED Hyperwall framed by two circular 4K screens. The Hyperwall show tells the story of our planet through videos and visualizations on subjects like air pollution, agriculture, and hurricanes. It also includes dashboards with real-time data and imagery of our planet.

"The data visualizations reflect how the study of Earth system science works, combining scientific models, satellite observations, and ground measurements from teams across the agency and across the government" said **Helen-Nicole Kostis** [NASA's Goddard Space Flight Center—*Science Visualizer*]. "The visualizations feature the latest data available, updated as often as six

Photo 1. Visitors observed the data-driven Hyperwall at the Earth Information Center on June 21, 2023, at the Mary W. Jackson NASA Headquarters building in Washington. **Photo credit:** Joel Kowsky/NASA

Photo 2. Local students take in the sights—and data—at an Earth Information Center student engagement event on June 23, 2023, at NASA HQ in Washington, DC. The Earth Information Center is a new immersive experience that combines live datasets with innovative data visualization and storytelling to show visitors how our planet is changing. **Photo credit:** Keegan Barber/NASA

minutes, with the goal of making scientific data accessible to people," Kostis said.

The Earth Information Center also includes a chandelier-like sculpture that depicts real-time satellite data transfers between space and ground receivers. Different patterns and speeds represent the amount of data being transferred and how quickly it reaches its destination.

Visitors can also track NASA's Earth science missions in real time by using the exhibit's touchscreen kiosk, which allows visitors to interact with a 3D globe and zoom in to areas of interest. They can view satellite imagery of recent natural events while also monitoring Earth's vital signs such as carbon dioxide concentrations, ozone holes, and sea level.

An exhibit titled "Space for Earth" invites viewers to experience Earth as an interconnected world, lacking boundaries or limits. Narrated by NASA astronaut **Drew Feustel** and retired NASA astronaut **Nicole Stott**, the seven-minute story is told in an immersive room with data visualizations and images projected onto the walls and floor to connect visitors to their home planet—see **photo 3**.

The EIC is part physical space and part virtual experience, and shows how NASA data can improve lives in the face of disasters, environmental challenges, and our changing world.

"For more than 60 years, NASA has used our vantage point of space to observe Earth with satellites and instruments aboard the International Space Station to collect vital, life-saving data," said **NASA Administrator Bill Nelson**, who led a ribbon cutting ceremony on June 21, 2023, to showcase the new EIC at NASA Headquarters—see **Photo 4**. "From firefighters that rely on NASA data for wildfire management to farmers who need to know when and where to plant crops, the Earth Information Center will help more people make informed decisions every day."

"NASA data powers resources across the U.S. and around the world, helping communities prepare for a changing climate," said **Kate Calvin** [NASA HQ—*Chief Scientist and Senior Climate Advisor*], who emceed the ribbon cutting. "The Earth Information Center benefits humanity by providing easily accessible and readily usable Earth information—helping people see our home planet the way NASA sees it."

Visit the hybrid exhibit **in person** at NASA Headquarters in Washington or **take a virtual tour of the Earth Information Center**. ■

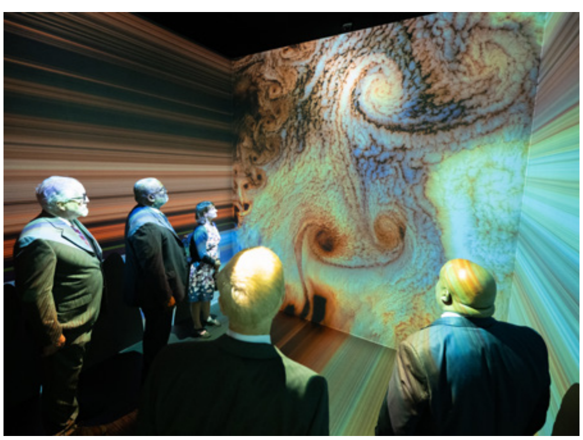

Photo 3. NASA Administrator Bill Nelson, Michael Morgan [NOAA—*Assistant Secretary of Commerce for Environmental Observation and Prediction*], Marlen Eve [USDA—*Deputy Administrator for the Agricultural Research Service at the U.S. Department of Agriculture*], and Eric Hooks [FEMA—*Deputy Administrator*] watch "Space for Earth," the data-driven, audio-visual installation in NASA's Earth Information Center. **Photo credit:** Joel Kowsky/NASA

Photo 4. NASA Administrator Bill Nelson (*center*) cuts the ribbon to open NASA's Earth Information Center alongside leaders from NASA, NOAA, USGS, USDA, USAID, EPA, and FEMA on June 21, 2023, at the Mary W. Jackson NASA Headquarters building in Washington, DC. **Photo credit:** Joel Kowsky/NASA

NASA Engages U.S. Farmers: Bringing Satellite Data Down to Earth

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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*.

Since the launch of the first Landsat satellite in 1972, NASA and its partners have mapped agriculture worldwide and provided key input into global supply outlooks that bolster the economy and food security. Now NASA is increasing its decades-long investment in U.S. agriculture through the launch of **NASA Acres**, a new consortium that will unite physical, social, and economic scientists with leaders in agriculture from public and private sectors. They will have the shared mission of bringing NASA data, science, and tools down-to-Earth for the benefit of the many people working to feed the nation.

"For decades, NASA has collected data in space to improve life on planet Earth," said **NASA Administrator Bill Nelson**. "Now these observations can be used not only to better understand our home, but to make climate data more understandable, accessible, and usable to help support agricultural business and benefit all humanity."

NASA Acres is commissioned under the agency's **Applied Sciences Program** and led by the University of Maryland. The consortium approach brings together public and private stakeholders and allows rapid actions in delivering NASA Earth observation data into the hands of U.S. farmers—see **Photo**.

"Farmers and ranchers are looking for information to help them make all sorts of decisions, from water use to what crops to plant and when," said **Karen St. Germain** [NASA Headquarters (HQ)—*Director of the Earth Science Division*]. "NASA is always looking for new ways to help people find and use science to inform their decisions, so we're very excited about this new consortium to help America's farmers use NASA Earth science data."

Initial projects include aggregating and analyzing years of satellite data with state-of-the-art machine learning and artificial intelligence tools. Such efforts could

Photo. Alyssa Whitcraft [University of Maryland, College Park—*NASA Acres Acting Director*] (*center,* yellow hat) meets with farmers. NASA Acres is a new consortium that will unite physical, social, and economic scientists with leaders in agriculture from public and private sectors. **Photo credit:** Catherine Nakalembe/NASA help optimize scheduling for fertilizer application and irrigation, support early detection of pests and disease, monitor soil health, and provide information tools to support local food production.

Other projects will focus on using open science to improve mapping capabilities that support user-driven applications.[1] The consortium will help us understand how U.S. agriculture is evolving and will shed light on effective management strategies to build economic, environmental, and productive resilience to global change.

U.S. farmers and ranchers have their own space agency

"While we have seen enormous value in the use of NASA data and tools, we also know that what works in one place can't just be picked up and dropped in a new place," said **Alyssa Whitcraft** [University of Maryland—*Director of NASA Acres*]. "To bring the greatest value of satellite data to U.S. agriculture, we have to start with place-based knowledge. Pairing that with satellite data unlocks powerful insight."

The U.S. is one of the world's top agriculture producers and exporters. According to the **U.S. Department of Agriculture**, the nation's farms, orchards, ranches, and supporting industries provide more than 10% of U.S. jobs and 5.4% of the U.S. gross domestic product.

In recent years, NASA has been working to ensure that members of the U.S. agriculture industry are connected directly to the agency's agriculture work, particularly through its Earth Applied Sciences program. In 2022, agency scientists including St. Germain made a "**Space for Ag**" tour across Nebraska and Kansas, and they have continued to have a presence at the nation's largest farming convention, the Commodity Classic.[2]

NASA Acres builds on the success of **NASA Harvest**, a globally focused consortium also based at the University of Maryland.

"We want farmers to know that their space agency has an agriculture program that is focused on understanding their needs and finding solutions with them," said **Brad Doorn**, who leads the **NASA agriculture program area** that oversees NASA Acres and Harvest.

Whitcraft emphasizes that NASA Acres relies first and foremost upon those closest to the land. NASA Acres is already working with small-scale, independent farmers in Maui County, Hawaii; specialty crop growers in California and New York; ranchers in Colorado; and farmers regenerating marginalized and degraded agricultural lands across the country.

"My mission has always been to feed people—not just in my home, and not just today, but looking ahead for the many generations to come," said Whitcraft. "U.S. agriculture is a cornerstone of the global food system, and it is awesome to have this opportunity with NASA to benefit my own 'backyard.'" ■

[1] To learn more about open science as it is being used in the context of NASA Earth science, 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].

[2] See page 5 of this issue to learn more about NASA's presence and exhibit at the 2023 Commodity Classic.

U.S.-German Satellites Show California Water Gains After Record Winter

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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 years of intense drought and diminishing groundwater, California just saw its greatest year-over-year water gains in two decades, according to data from the Gravity Recovery and Climate Experiment Follow-On (**GRACE-FO**) satellite mission, a partnership between NASA and the GeoForschungsZentrum (GFZ) [German Research Centre for Geosciences]. This past winter's bonanza of atmospheric rivers alleviated some of the water deficit that the state incurred during periods of drought over the last 10 years—which included the three driest years on record in California—see **Figure 1**, *below*.

Early data shows the greatest net gain of water over the winter in nearly 22 years—but the state's groundwater levels still suffer from the effects of years of drought. Think of the state's Central Valley region as a giant swimming pool: GRACE-FO measurements include all the water contained in the lakes, rivers, soil, snowpack, and underground aquifers within that region. Between October 2022 and March 2023, storms provided enough water to raise the amount of water within the "swimming pool" by ~52 cm (20 in). That's about twice as much as the average winter water gain since satellite-based water storage measurements began in 2002 with the first **GRACE** mission—see **Figure 2** on page 29.

While surface water basins are filling, underground stores of fresh water (*aquifers*) that are tapped for irrigation and other needs could take years to fully recharge. "One good winter of rain and snow won't make up for years of extreme drought and extensive groundwater use," said **Felix Landerer** [NASA/Jet Propulsion Laboratory (JPL)—*GRACE-FO Project Scientist*]. The GRACE-FO team will continue to track how California's water storage evolves through the summer after the snowpack melts and water levels in the state's lakes, rivers, and reservoirs start to recede during drier weather.

The observations were made possible through the unique sensing approach taken by both GRACE missions. As water moves around—in the form of ocean currents, falling rain, shifting groundwater, ice,

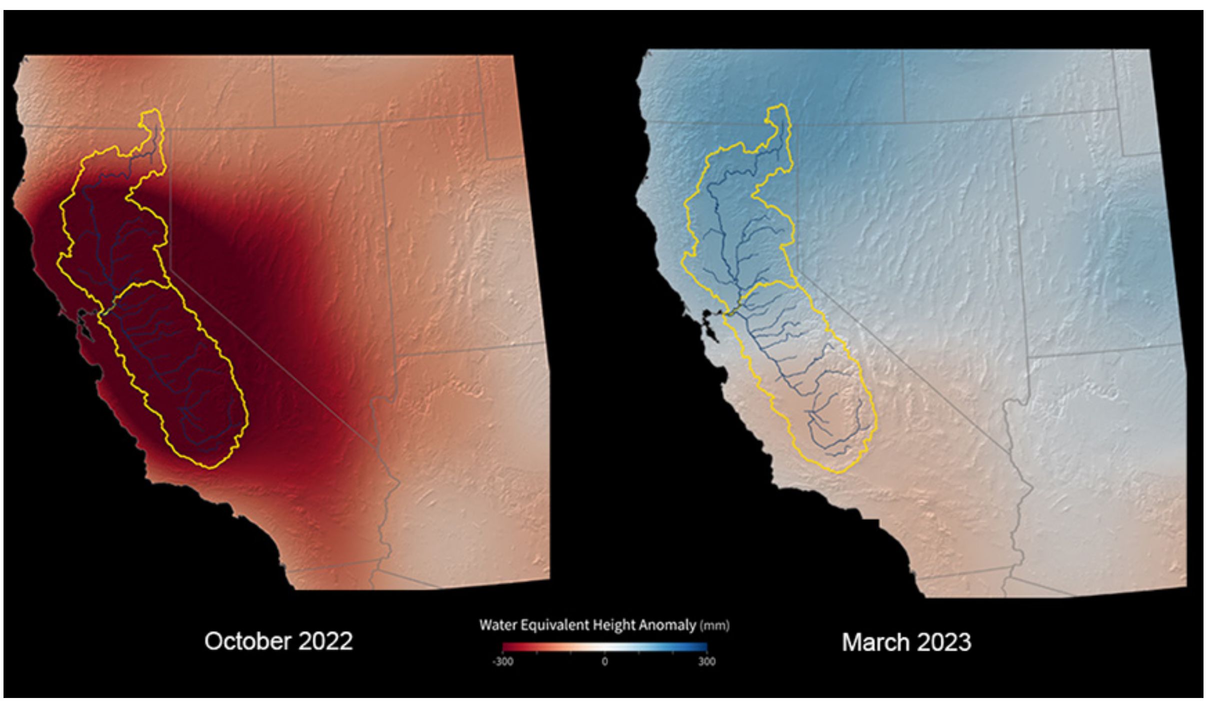

Figure 1. Thanks to a wet winter, California saw tremendous gains in the amount of water in the San Joaquin, Sacramento, and Tulare River basins [*outlined in yellow*] from October 2022 to March 2023, GRACE-FO data shows. The measurement includes water in lakes, rivers, reservoirs, snowpack, and groundwater aquifers. **Figure credit:** NASA's Scientific Visualization Studio

and so on—it alters the planet's mass near the surface, which changes Earth's gravitational pull ever so slightly. GRACE-FO measures these subtle changes, enabling researchers to estimate changes in the total volume of water in an area—see **Figure 3**, *below*. ▬

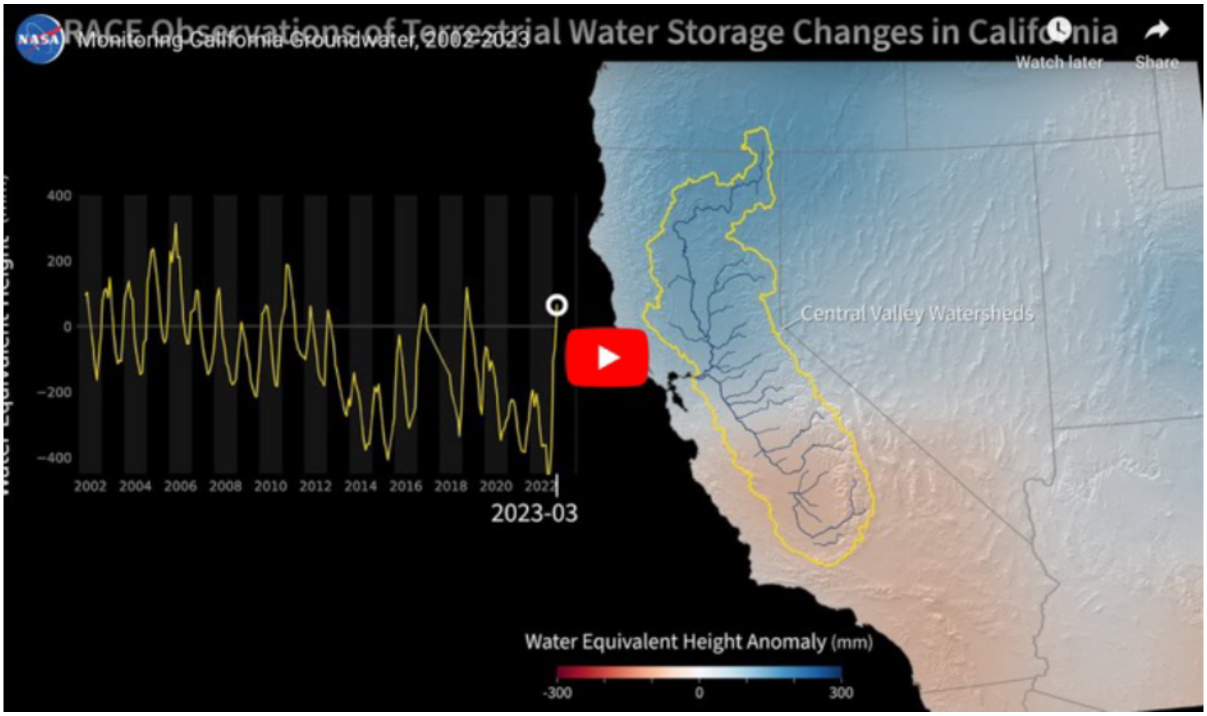

Figure 2. This animation shows changes in the total amount of water within the California region [*outlined in yellow*]—including the Sacramento, San Joaquin, and Tulare River basins—from 2002 to 2023. The zero line on the graph represents the average amount of water in the region from 2004 to 2010. **Figure credit:** NASA's Scientific Visualization Studio

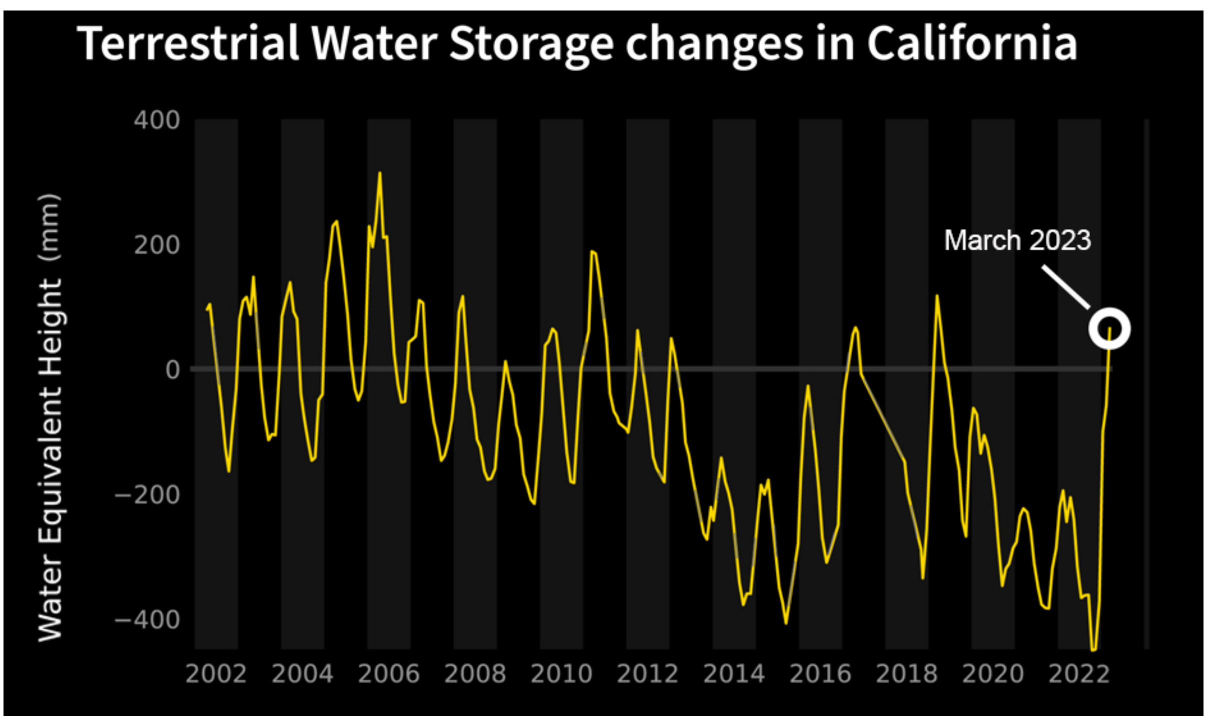

Figure 3. The line graph shows seasonal changes in the total amount of water contained in California's lakes, rivers, reservoirs, snowpack, and groundwater from 2002 to 2023. Note that there was a data gap from late 2017 to early 2018, which coincides with the decommissioning of the GRACE mission and the launch of its successor, GRACE-FO. **Figure credit:** NASA's Scientific Visualization Studio

NASA Researchers Detect Tsunamis by Their Rumble in the Atmosphere

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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*.

Triggered by earthquakes, undersea volcanoes, and other Earth-shaking forces, tsunamis can devastate coastal communities. And when it comes to providing advance warning, every second counts. Scientists at NASA/Jet Propulsion Laboratory (JPL) are testing a novel approach to detect—from the far reaches of the atmosphere—the ocean's deadliest waves.

Called **Global Navigation Satellite System (GNSS) Upper Atmospheric Real-time Disaster Information and Alert Network** [GUARDIAN], the experimental monitoring system taps into data from clusters of global positioning system (GPS) and other wayfinding satellites orbiting our planet. Collectively, these clusters are known as GNSS. Their radio signals travel to hundreds of scientific ground stations around the world, and these data are crunched by JPL's Global Differential GPS (GDGPS) network, which improves **real-time positional accuracy** down to a few inches (~10 cm).

The new system sifts the signals for clues that a tsunami has arisen somewhere on Earth. How does it work? During a tsunami, many square miles (or square kilometers) of the ocean surface can rise and fall nearly in unison, displacing a significant amount of air above it. The displaced air ripples out in all directions in the form of low-frequency sound and gravity waves. Within several minutes, these vibrations reach the topmost layer of atmosphere: the Sun-cooked, electrically charged ionosphere. The ensuing clash of pressure waves with charged particles can distort the signals from nearby navigational satellites ever so slightly—see **Figure**.

While navigation tools usually seek to correct for such ionospheric disturbances, scientists can use them as a lifesaving alarm bell, noted **Léo Martire** [JPL]. "Instead of correcting for this as an error, we use it as data to find natural hazards," Martire said.

Fastest Monitoring Tool of Its Kind

The technology is still maturing, said Martire, who co-chairs a task force within the United Nations' **International Committee on GNSS** that is exploring the use of navigational satellite systems to enhance early warning strategies. Currently, the GUARDIAN near-real-time output must be interpreted by experts trained to identify signs of tsunamis. But already it is one of the fastest monitoring tools of its kind: **Within 10 minutes** it can produce a kind of snapshot of a tsunami's rumble reaching the ionosphere. And it could potentially provide as much as an hour of warning, depending on the distance of the tsunami origin from shore.

"We envision GUARDIAN one day complementing existing ground- and ocean-based instruments such as seismometers, buoys, and tide gauges, which are highly effective but lack systematic coverage of the open ocean," says **Siddharth Krishnamoorthy** [JPL]. Scientists affiliated with NASA's Disasters program currently **use ground-based instruments** at GNSS stations for faster tsunami detection.

"When there is a large earthquake near the ocean, we want to quickly know the magnitude and characteristics of the earthquake to understand the likelihood that a tsunami will be generated, and we want to know if a tsunami was indeed generated," said **Gerald Bawden** [NASA Headquarters (HQ)—*Program Scientist for Earth's Surface and Interior*]. "Today there are two ways to know if a tsunami was generated before it makes landfall—the National Oceanic and Atmospheric Administration's (NOAA) **Deep Ocean Assessment and Reporting of Tsunamis** (DART)

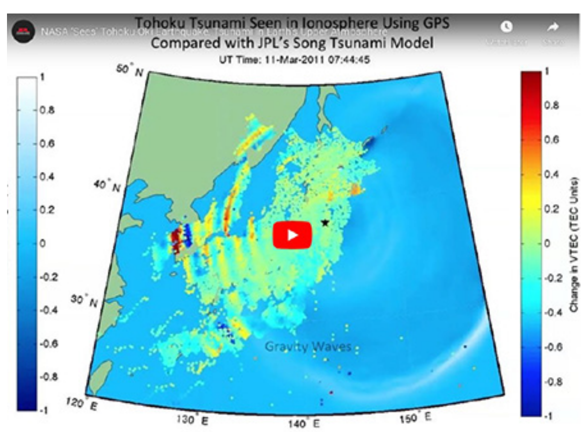

Figure. This animation shows how waves of energy from the Tohoku-Oki earthquake and tsunami of March 11, 2011, pierced Earth's ionosphere in the vicinity of Japan, disturbing the density of electrons. These disturbances were monitored by tracking GPS signals between satellites and ground receivers. **Figure credit:** NASA/JPL buoys and GNSS-ionosphere observations. There are a limited number of buoys and they are very expensive, so systems like GUARDIAN have the potential to complement current warning systems."

Right now, the GUARDIAN team is focused on the Pacific Ocean's geologically active *Ring of Fire*. About 78% of the more than 750 confirmed tsunamis between 1900 and 2015 occurred in this region, according to a **historical database** maintained by the National Oceanic and Atmospheric Administration (NOAA). GUARDIAN currently monitors a little over half of the region of interest in the Pacific.

The GUARDIAN team is developing a website to allow experts to explore the state of the ionosphere in near real time by studying individual satellite station links on the GNSS network. Users can access the data from about 90 stations around the Pacific Ring of Fire and discover signals of interest within minutes of an event occurring. The team aims to expand coverage and refine the system to a point where it could automatically flag tsunamis and other hazards, including volcanic eruptions and earthquakes. ■

Earth Science Meeting and Workshop Calendar

NASA Community

September 12–13, 2023
ROSES SAGE III/ISS Science Team Meeting
Atlanta, GA
Information forthcoming

September 18–22, 2023
PMM Science Team Meeting
Minneapolis, MN
Invitation only

October 16–18, 2023
DSCOVR Science Team Meeting
NASA/GSFC, Greenbelt, MD

October 17–19, 2023
CERES Science Team Meeting
NASA/GISS, New York, NY
Meeting details forthcoming

November 7–11, 2023
OST Science Team Meeting
San Juan, Puerto Rico

Global Science Community

July 30–August 4, 2023
Asia Oceania Geosciences Society (AOGS)
Singapore

August 6–11, 2023
Ecological Society of America (ESA)
Portland, OR

August 13–17, 2023
American Chemical Society (ACS)
San Francisco, CA

October 11–15, 2023
Historically Black Colleges and Universities (HBCU) Climate Change Conference
New Orleans, LA

October 15–18, 2023
Geological Society of America (GSA)
Pittsburgh, PA

NASA Earth Science in the News

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EDITOR'S NOTE: Presented in this column are summaries of articles that have been published on *nasa.gov* that have subsequently been reported on by other media outlets.

Desert Dust Plays a Vital Role in Fertilizing Phytoplankton Growth in Oceans, June 26, 2023, *scitechdaily.com*. In a new study published in ***Science***, a team of researchers from Oregon State University (OSU), the University of Maryland Baltimore County (UMBC), and NASA combined satellite observations with an advanced computer model to home in on how mineral dust from land fertilizes the growth of phytoplankton in the ocean. For the past few decades, scientists have been observing *natural ocean fertilization events*—episodes when plumes of volcanic ash, glacial flour, wildfire soot, and desert dust blow out onto the sea surface and spur massive blooms of phytoplankton—see **Figure 1**. But beyond these extreme events, there is a steady, long-distance rain of dust particles onto the ocean that promotes phytoplankton growth just about all year and in nearly every basin.

According to the new study, dust deposition onto the ocean supports about 4.5% of yearly global export production—a measure of how much of the carbon phytoplankton take up during photosynthesis sinks into the deep ocean. However, this contribution approaches 20–40% in some ocean regions at middle and higher latitudes. Dust particles can travel thousands of miles before falling into the ocean, where they nourish phytoplankton long distances from the dust source, said study co-author **Lorraine Remer** [UMBC]. "We knew that atmospheric transport of desert dust is part of what makes the ocean 'click,' but we didn't know how to find it," she said. The team analyzed 14 years of ocean color measurements collected by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua[1] satellite from 2003 to 2016. Tracing distinct signatures

[1] MODIS is a key instrument aboard the **Terra** *and* **Aqua** satellites.

Figure 1. This image, acquired on April 8, 2011, with the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on NASA's Terra satellite, shows Saharan dust over the Bay of Biscay. A phytoplankton bloom makes the water appear bright green and blue. Sediment is likely contributing to some of the color, especially in coastal areas. **Credit:** NASA Earth Observatory image by Wanmei Liang

in ocean color, they were able to determine not only when and where phytoplankton blooms occurred, but also how healthy and abundant they were, based on the concentration of chlorophyll. To determine if the phytoplankton were responding to desert dust, the team compared their ocean color findings with output from NASA's **Goddard Earth Observing System** (GEOS) model of dust deposition events for the same time period. They found that even modest amounts of desert dust increased the mass and improved the health of phytoplankton blooms almost everywhere they looked. "We observed that the phytoplankton response wasn't just happening in iron-poor areas of the ocean," said co-author **Hongbin Yu** [NASA's Goddard Space Flight Center]. "The responses were occurring all over the world. Add a little bit of nutrients and you've got something happening in the water." ■

NASA Spots El Niño Precursor from Space, May 21, 2023, *space.com*. The most recent sea level data from the U.S.–European satellite **Sentinel-6 Michael Freilich** (S6MF) indicates early signs of a developing El Niño across the equatorial Pacific Ocean. The data show Kelvin waves—which are roughly 2–4 in (5–10 cm) high at the ocean surface and hundreds of miles wide—moving from west to east along the Equator toward the west coast of South America. When they form at the Equator, Kelvin waves bring warm water, which is associated with higher sea levels, from the Western Pacific to the Eastern Pacific—see **Figure 2**, *below*.

"When we measure sea level from space using satellite altimeters, we know not only the shape and height of water, but also its movement, like Kelvin and other waves," said **Nadya Vinogradova Shiffer** [NASA HQ—*S6MF Program Scientist and Manager*]. "Ocean waves slosh heat around the planet, bringing heat and moisture to our coasts and changing our weather." Satellites like S6MF detect Kelvin waves with a radar altimeter, which uses microwave signals to measure the height of the ocean's surface. When the altimeter passes over areas that are warmer than others, the data will show higher sea levels—see **Figure 3**, on page 34.

"We'll be watching this El Niño like a hawk," said **Josh Willis** [NASA/Jet Propulsion Laboratory (JPL)—*S6MF Project Scientist*]. "If it's a big one, the globe will see record warming, but here in the Southwest U.S. we could be looking at another wet winter, right on the heels of the soaking we got last winter." ■

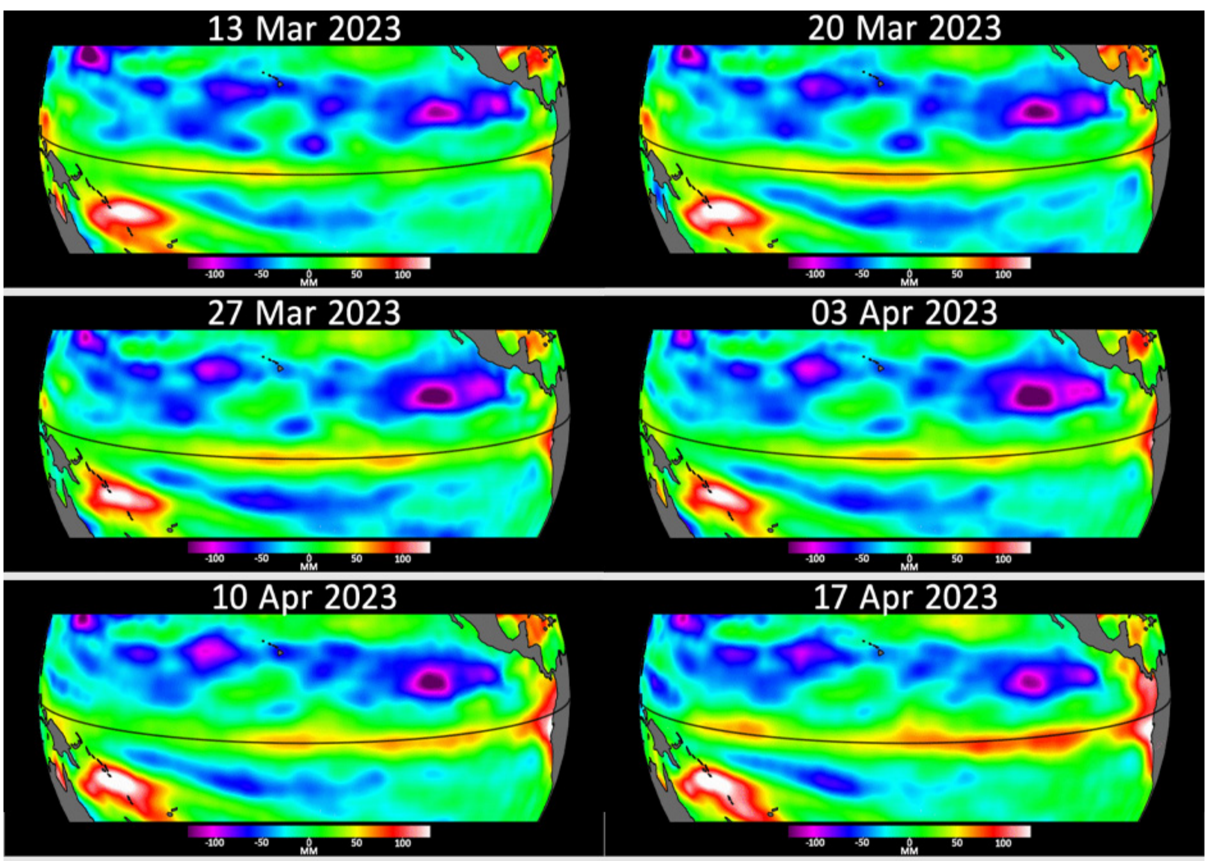

Figure 2. This animation shows a series of waves, called Kelvin waves, moving warm water across the equatorial Pacific Ocean from west to east during March and April. The signals can be an early sign of a developing El Niño and were detected by the Sentinel-6 Michael Freilich sea-level-measuring satellite. **Credit:** NASA/JPL-Caltech

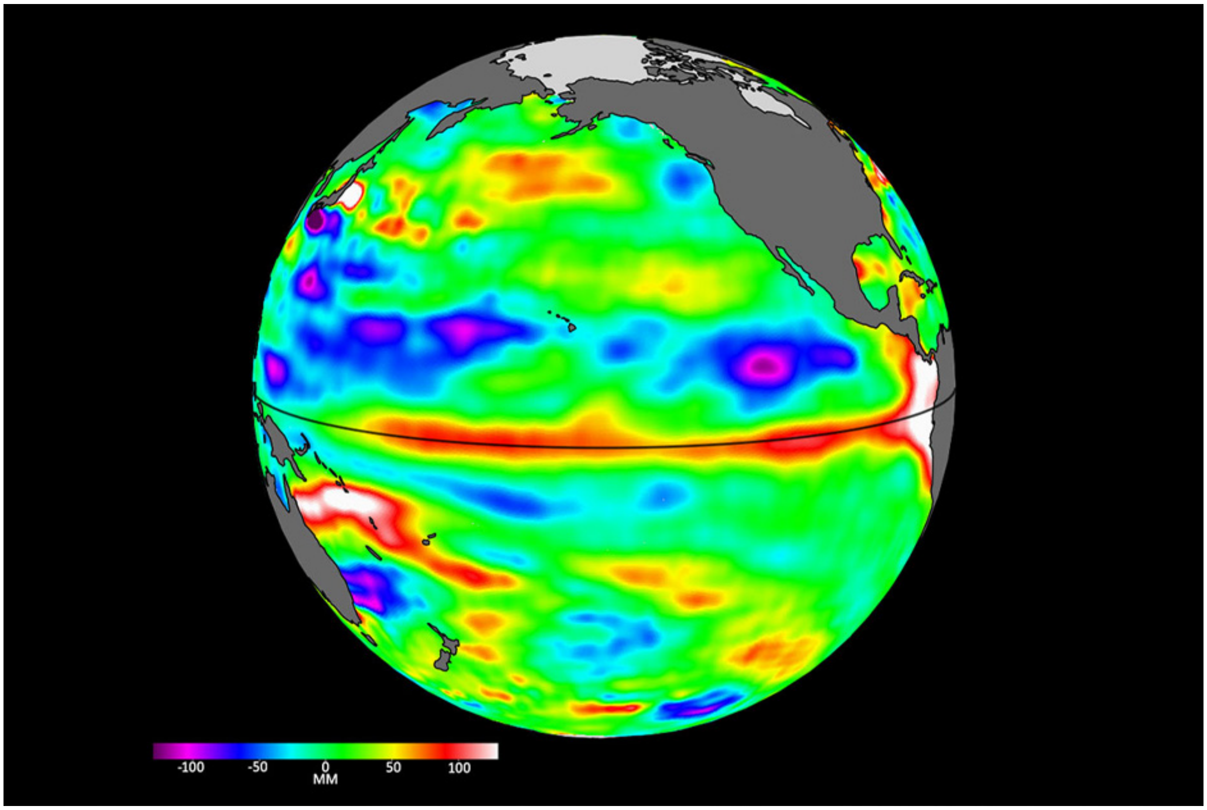

Figure 3. Sea level data from the Sentinel-6 Michael Freilich satellite on April 24, 2023, shows in red and white relatively higher and warmer ocean water at the Equator and the west coast of South America. Water expands as it warms, so sea levels tend to be higher in places with warmer water. **Credit:** NASA/JPL-Caltech

Satellite Data, Applications Flowing Through SERVIR to Southeast Asia, May 7, 2023, *spaceref.com*. Historically, reservoir measurements or flood warnings along the Mekong River—which more than 50 million people across Southeast Asia depend on for drinking water and agriculture—came from stream gauges and limited or outdated satellite data. But in recent years, scientists in the region have worked with colleagues from NASA, the U.S. Agency for International Development (USAID), and the Asian Disaster Preparedness Center (ADPC) to build tools that process data from Earth-observing satellites to better predict extreme rainfall and track reservoir levels. "Our collaboration enhanced the accuracy and lead time of the Mekong River Commission's flood forecasting," said **Anoulak Kittikhoun** [Mekong River Commission—*CEO*]. "As climate change intensifies and development accelerates, we will work together to get better information into the hands of farmers and communities in order to make them more resilient and adaptable." It is a prime example of the work NASA and USAID have been doing to make Earth science data more accessible and useful in countries around the world. The work springs out of **SERVIR**, a NASA–USAID initiative that builds collaborative projects and conducts training to help bring Earth science data into regional, national, and local decision making. "Collaborative development leads to geospatial services that fit community needs," said **Karen St. Germain** [NASA Headquarters (HQ)—*Director of the Earth Sciences Division*]. A series of productive collaborations inspired the partners to expand their work in the region with the renamed SERVIR–Southeast Asia. "We made such an impact in recent years as SERVIR-Mekong, and I'm excited about being able to work alongside more partners to enable their use of NASA's Earth science to address their most pressing environmental issues," said **Nancy Searby** [NASA HQ—*SERVIR Program Manager*]. Beyond the river-monitoring tools, scientists created a tool to automatically interpret atmospheric data from NASA satellites and share the results through Thailand's Pollution Control Department. Named the **Mekong Air Quality Explorer**, the tool includes a mobile app that authorities use to identify sources of heavy smoke and pollution, track air flow, and help officials send out public health warnings about poor air quality. Additional new tools will track forest loss and help rice growers prepare for climate change. ■

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