Over Thirty Years Reporting on NASA's Earth Science Program

The Earth Observer

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The Editor's Corner

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It is early 2024 as this issue of *The Earth Observer* is published online and we have exciting news to share about the successful launch of a new NASA mission. On February 8, 2024, at 1:33 AM EST, NASA's **Plankton, Aerosol, Cloud ocean Ecosystem** (PACE) mission took to the skies aboard a Falcon 9 rocket launched from Cape Canaveral Space Force Base in Florida—see photo on page 4. NASA confirmed signal acquisition from the satellite about five minutes after launch, and the spacecraft is performing as expected. Now the PACE team can turn its attention to testing the instruments and preparing them for science operations.

Managed by NASA's Goddard Space Flight Center (GSFC), the PACE payload includes a state of the art **Ocean Color Instrument** (OCI) designed and built at GSFC—which will continue NASA's more than 40-year time series of ocean color measurements. PACE also flies two polarimeters: the **Hyper-Angular Rainbow Polarimeter #2** (HARP2) designed and built by the University of Maryland, Baltimore County (UMBC) and the **Spectro-polarimeter for Planetary Exploration one** (SPEXone) developed and built by a Dutch consortium led by SRON Netherlands Institute for Space Research, Airbus Defence, and Space Netherlands. These two instruments will make independent measurements of the angular distribution of polarized reflected sunlight. While such details are invisible to the naked eye, they are crucial for understanding the size, composition, and concentration of atmospheric particles (or *aerosols*) and clouds. A **Visualization** (also included in the "NASA Earth Science in the News Column" on page 41 of this issue) provides more details on the role of the two PACE polarimeters, some applications for polarimetry data, and how the PACE team will process the vast amounts of data generated by this mission.

The inclusion of these two polarimeters on PACE is the fulfillment of a long-desired capability for NASA Earth science. Building on the heritage of several polarimeters used for planetary exploration in the 1970s and 1980s, an Earth Observing Scanning Polarimeter (EOSP) was part of the original Earth Observing System platform concepts in the early 1990s. While EOSP was ultimately not included as part of the EOS flight hardware, NASA's Goddard Institute for Space Studies (GISS) developed a suborbital version called the Research Scanning Polarimeter (RSP), which has flown in various campaigns since 1999 to test polarimetric techniques. An updated version of EOSP (renamed the Aerosol Polarimetry Sensor, or APS) would have been part of NASA's Glory mission, which failed to reach orbit in 2011. Finally, nearly 13 years later with the launch of PACE, not one but two space-based polarimeters will be in operation.[1]

[1] The POLDER polarimeter was flown by CNES on their PARASOL satellite (launched in 2004) that was an early member of the International A-Train, as well as on two earlier Japanese ADEOS missions.

continued on page 2

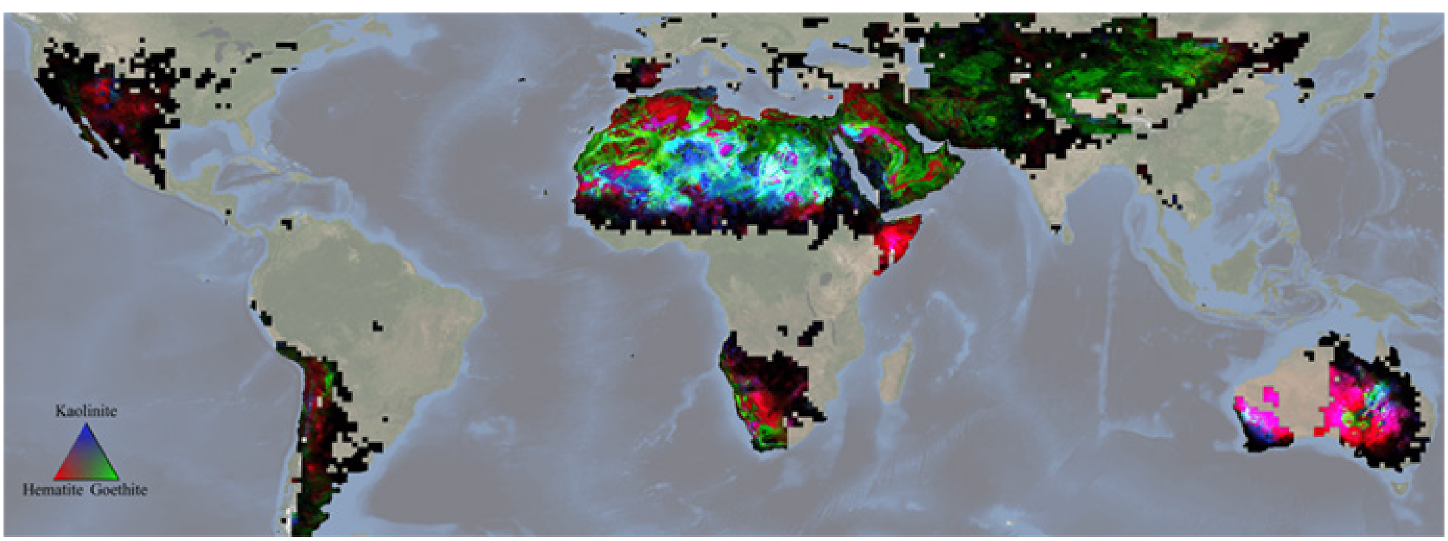

Figure. NASA's Earth Surface Mineral Dust Source Investigation (EMIT) mapped hematite, goethite, and kaolinite in North Africa and the Arabian Peninsula. These three dust source minerals are among 10 key substances the mission studied that can influence climate when high winds transport them into the atmosphere. **Image Credit:** NASA/JPL

In This Issue

My congratulations to the entire PACE team for a successful launch. As with many missions, the PACE launch is the culmination of years of development and would not have become reality without the dedicated efforts of many individuals who have worked hard to reach this point and who will continue to work as the mission unfolds. The science and applications communities eagerly await the data from this new mission.

Speaking of applications, to ensure the PACE mission and its anticipated data products meet the needs and objectives of applied-user and stakeholder communities, NASA's **PACE Applications Program** has been established to build partnerships between data product developers, data distributors, and data users. The latest in a series of successful PACE Applications Workshops took place in September 2023. The workshop offered opportunities for participants to connect, contribute, and collaborate. Prior to the event, workshop organizers polled registrants to share their backgrounds, expertise, interests, and demographics to facilitate a relevant workshop with engaging conversations. To learn more about the PACE Applications Workshop, see the summary on page 25 of this issue.

Staying on the subject of aerosols, NASA's Earth Surface Mineral Dust Source Investigation (EMIT) mission closed out 2023 with an exciting new achievement, as it produced the first comprehensive maps of the world's mineral dust-source regions—see **Figure** on Front Cover. The maps are based on data from the year ending November 2023 and show concentrations of important minerals in Earth's dry regions.

Launched to the International Space Station in 2022, EMIT is an imaging spectrometer developed by NASA/Jet Propulsion Laboratory (JPL). The mission collected billions of measurements and mapped key minerals that can affect climate when lofted into the air as dust storms (through their influence on *aerosol* composition), thus providing scientists with crucial new information to model related impacts. To date, the mission has captured more than 65,000 *scenes*, or 50 x 50-mi (80 x 80-km) spectral-image-cubes of the surface, including arid regions within a 6900-mi (11,000-km) wide belt around Earth's mid-section below the International Space Station. Detailed maps of surface composition are derived from the billions of spectroscopic measurements within this data set that is openly available from the **Land Processes Distributed Active Archive Center** (LP DAAC).

During its 17 months in orbit, EMIT has demonstrated additional capabilities beyond its primary mission, including **measuring plumes of methane** and carbon dioxide being emitted by landfills, oil facilities, and other localized sources.

Closer to the ground, NASA's Goddard Space Flight Center's (GSFC) **Southern Hemisphere Additional OZonesondes** (SHADOZ) network, which coordinates balloon-borne ozonesonde launches from 14 tropical sites through global partnerships, has reached two milestones this year: 25 years of operation and the archiving of 10,000 ozone and pressure-temperature-humidity datasets.

The project was initiated in 1998 by NASA–GSFC, NOAA's Global Monitoring Division, and international co-investigators. The collective data set—derived from the 14 stations launching ozonesondes in the SHADOZ network—provides the first climatology of stratospheric and tropospheric tropical ozone in the equatorial region, enhancing validation studies aimed at improving satellite remote sensing techniques for tropical ozone estimations, and serves as an educational tool to students, especially in participating countries.

The 2023 archive is expected to hit 400 profile pairs from 14 stations, bouncing back from reduced operations during the COVID-19 pandemic.

Celebration of both its 25-year milestone and collection of its 10,000th total ozone profile in 2023 offered an opportunity to reflect on the transformative scientific contributions of the SHADOZ program. To read more about the SHADOZ network's origins, history, current network status, and recent scientific accomplishments, turn to page 13 of this issue.

Shifting focus to NASA's education and public outreach activities, since its establishment in 2016, NASA's **Science Activation (SciAct) program** has implemented a collective-impact, network-of-networks approach, with teams reporting 525 active external partners as of 2022. The SciAct program supports, leads, and coordinates collaboration across a cooperative, nationwide network of 50 competitively selected SciAct teams and NASA infrastructure activities.

These teams of community-based learning providers, educators, and experts work together to connect diverse learners of all ages with exciting NASA content and authentic science experiences. In 2022, the Science Activation program facilitated 52 million learner interactions in the U.S. and a quarter-million abroad. The program is now working to bolster its already impressive reach and engagement successes through enhanced communications and social media strategies that leverage NASA's extensive networks. To read more about the SciAct program's range of resources and opportunities that invite learners of all ages to participate in authentic science, turn to page six of this issue.

Every NASA mission is designed and funded for a projected operation lifetime. Missions that are still functional at the end of their primary operational phase are asked to submit proposals for a Senior Review, currently on a three-year cadence, in which a science community panel and sub-panels are convened to "evaluate the scientific performance of each mission and the continued relevance of each mission to the NASA Science Strategic Plan." Performance factors include scientific merit, national needs, the technical status of the mission, and budget efficiency.[2]

The most recent Earth Science Senior Review took place during 2023, with proposals submitted in April for extensions in fiscal years 2024–2026. Twelve NASA Earth Science missions in extended operations were evaluated: **Aqua**, **Aura**, **CYGNSS**, **DSCOVR** (Earth Science Instruments: **EPIC** and **NISTAR**), **GRACE Follow-On**, **GPM**, **ICESat-2**, **OCO-2**, **SAGE III on ISS**, **SMAP**, **Terra**, and **TSIS-1**. Of these, eight missions (DSCOVR, GRACE Follow-On, GPM, ICESat-2, OCO-2, SAGE III, SMAP, and TSIS-1) were endorsed for extension for the fiscal years 2024–2026 and are expected to be invited to the 2026 Senior Review for further extension. CYGNSS was extended through fiscal year 2025—with continued operations beyond fiscal year 2025 contingent upon the team addressing the findings of the 2023 Senior Review and the successful completion of an interim review to assess their progress. Aqua, Aura, and Terra were extended to their estimated natural end of life based on the remaining fuel/power in their drifting orbits.[3] In addition, Out-of-Cycle Senior Reviews for four other ISS missions (**ECOSTRESS**, **EMIT**, **GEDI**, and **OCO-3**) took place in late 2022 and 2023.[4]

The **2023 Earth Science Senior Review panel report for the 12 in-cycle missions** was released in October 2023. The panel report emphasizes that the challenge of supporting "existing missions and their data products beyond their design lives as well as supporting the new missions identified in the [2017 Earth Science] Decadal Survey is entirely the product of the success of NASA's Earth Science Division (ESD)." Congratulations to all the mission teams for their hard work in preparing proposals, and special thanks to all review panel members for their willingness to participate in this critical activity. The **ESD response for all out-of-cycle and in-cycle missions** is also available.

Last but certainly not least, I'm happy to report the successful completion of a long-standing goal for *The Earth Observer Team*. Readers now have access to the **complete online archive** spanning the last 35 years of newsletter publications—dating to the very first issue published in March 1989! Nearly every past "hard copy" issue has been meticulously optically scanned and uploaded to our archives page,[5] and an effort to improve search engine optimization (SEO) for the early newsletter content is underway, thereby enhancing the archival value of the nascent years of NASA Earth Science.

[2] Quote and other information in this paragraph is from **Senior Reviews for Earth Operating Missions**. Reports on the current and previous Earth Science Senior Reviews can be downloaded from this website.

[3] To learn more about the drifting orbits of these missions, see **NASA Holds Discussions about the Future of the EOS Flagship Missions** in the January–February 2023 issue of *The Earth Observer* [**Volume 35**, **Issue 1**, pp. 13–17].

[4] All undefined acronyms in this paragraph refer to mission and instrument names that are well known to most readers—and easily referenced at the linked websites. The one exception is ISS, which stands for International Space Station.

[5] The attentive reader may notice there is one issue missing from the archives page: November 1990 [**Volume 2**, **Issue 9**]. We would like to track down a copy this issue if possible; please see the advertisement on page 5 of this issue for more information.

Photo. NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) spacecraft, atop a SpaceX Falcon 9 rocket, successfully lifts off from Space Launch Complex 40 at Cape Canaveral Space Force Station in Florida at 1:33 AM EST February 8, 2024. PACE is NASA's newest Earth-observing satellite that will help increase our understanding of Earth's oceans, atmosphere, and climate by delivering hyperspectral observations of microscopic marine organisms called phytoplankton, as well as new data on clouds and aerosols. **Photo credit:** NASA/Kim Shiflett

This achievement aligns with the release of this issue of *The Earth Observer*—which will be the final bimonthly PDF issue published. During 2023, the team planned its transition to posting individual articles online and has been working to transition to a new content management system (CMS). The new CMS is projected to debut no earlier than March 2024—which coincides with the 35th anniversary of *The Earth Observer*. We aim to notify our readers about freshly uploaded content on our website through weekly email alerts that include a direct link to our newsletter in your inbox. Our commitment is to keep subscribers informed about the latest developments through various communication channels, which we will notify readers of as they become available. Please see the *Update from the Executive Editor* on **page 32** for more information about the production team's transition to posting individual articles online. ■


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The Earth Observer
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An EOS Periodical of Timely News and Events
Vol. 2, No. 9
November 1990
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Handle with care.
If found, CONTACT: Dalia Kirshenblat,
dalia.p.zelmankirshenblat@nasa.gov
DETAILS:
As explained in "The Editor's Corner" of this issue, coincident with the final pdf issue being produced, *The Earth Observer* has extended its online archive of issues all the way back to the first issue published nearly 35 years ago in March 1989. However, one hard copy appears missing from our records: **November 1990 [Volume 2, Issue 9]**. We hope one of our long-term readers might still have a copy of this issue. If so, please reply to Dalia (Managing Editor) so we can arrange to get a copy of the elusive issue, scan it, and complete our online collection.

NASA Earth Science and Education Update: Introducing the Science Activation Program

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Introduction

For many years, *The Earth Observer* ran a regular *NASA Earth Science Education and Public Outreach Update* column, the last of which appeared in the May–June 2017 issue of *The Earth Observer.*[1] At that time, NASA Science Education communications had moved to **Science WOW**!—a Weekly On Wednesday's email listserv. Science WOW! ran from July 2016–April 2018, at which time it, too, was discontinued based on a review of audience metrics. In the more than five years since *Science Wow!* was discontinued, however, NASA science education has not gone dark. In fact, there is a vigorous community—called the *Science Activation* (SciAct) program—working to share NASA science with learners of all ages—see **Photo 1**. In 2022 alone, SciAct facilitated over 50 million learner interactions with NASA science, content, and experts.

Photo 1. The SciAct community gathered for its most recent annual meeting in November 2023. **Photo credit:** NASA

The following article briefly summarizes the history of NASA's science education and outreach activities leading up to the establishment of NASA's SciAct program. It then describes the evolution of SciAct, followed by the variety of ways SciAct helps learners get "activated." It ends with a list of the SciAct programs that are directly relevant to Earth science.

History of NASA's Science Outreach and Education Activities

Prior to 1993, NASA science education and public outreach activities took place on more of an *ad hoc* basis in which individual NASA centers and missions responded to regional needs. From 1993–2014 NASA Science education and public outreach (EPO) activities were aligned to individual missions. Under that model, each science mission was directed to devote 1% of its total budget to EPO activities. While this model resulted in impactful work tied to NASA mission science, it ultimately led to *silos*, with each mission operating separately and sometimes in competition with one another. This inevitably led to duplication of efforts.

As a result, the White House Office of Management and Budget (OMB) zeroed out EPO funding for individual missions beginning with Fiscal Year 2015, requiring Science Mission Directorate (SMD) leadership to come up with a new approach. The result was SciAct—a competitive program that would work to collaboratively meet the needs of learners in all 50 states. SciAct has required a culture change from

[1] See **NASA Science Mission Directorate – Science Education and Public Outreach Update** in the May–June 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 3**, p. 38]. Prior to 2010, the column was known as the "Science Education Update."

the previous model, which has taken time to take hold. The ultimate Vision of the program is: *To increase learners' active participation in the advancement of human knowledge*.

SciAct focuses on four top-level objectives to advance this vision. They are to:

1. enable STEM education;
2. improve U.S. science literacy;
3. advance national education goals; and
4. leverage through partnerships.

The SciAct **Impact Reports** for 2021 and 2022 detail this vision and progress toward achieving these goals.

SciAct began in 2015 with a stand-alone Cooperative Agreement Notice (CAN) and moved into the Research Opportunities in Space and Earth Sciences (ROSES) omnibus solicitation at the five-year mark.

Evolution of NASA's Science Activation Program

SciAct began in 2015 with a stand-alone Cooperative Agreement Notice (CAN) and moved into the Research Opportunities in Space and Earth Sciences (ROSES) omnibus solicitation at the five-year mark. SciAct solicitations and selections are summarized in **Table 1**.

Table 1. Dates of and links to details on key solicitation and selections related to NASA's SciAct.

Year	Solicitations	Selections
2015	**Science Education Cooperative Agreement Notice (CAN)**	**27 projects**
2020	**Science Education CAN** extension opportunity	**18 continuing projects**
2020	**ROSES E.6. Science Activation Program Integration**	**9 projects** added to portfolio
2021	**ROSES F.6 Science Activation Program Integration**	**13 additional projects** selected in priority areas
2024	Next planned solicitation to refresh the SciAct portfolio	Draft to be released February 14, 2024.

A late 2014 National Academies of Sciences, Engineering, and Medicine (NASEM) workshop influenced the development of the original Science Education CAN. The report, **Sharing the Adventure with the Student**, includes a summary of the workshop. In recognition of the importance of building relationships to reach learners through community-based organizations, NASA intiated SciAct as a five-year program—with the option of adding five more years. In 2019, the NASEM conducted a rigorous assessment of the program to guide it into the second five-year period. The resulting **assessment report** contains 15 conclusions and 7.5 recommendations implemented by the program. A **second NASEM assessment** is in progress now to guide the program past the 10-year mark.

How SciAct Gets Learners "Activated"

In pursuit of its overarching goal of increasing learners' participation in the advancement of human knowledge, SciAct pursues a variety of activities. These are discussed in the subsections that follow.

Connect and Collaborate: A Collective Impact Approach

Since its inception in 2016, the SciAct program has adopted a *collective-impact*, network-of-networks approach—illustrated in **Figure 1**. A small group at NASA serves as the *backbone organization* that supports, leads, and coordinates collaboration across a cooperative, nationwide network of ~50 competitively-selected SciAct teams and NASA infrastructure activities. These teams of community-based learning providers, educators, and experts work together to connect diverse learners of all ages with NASA science experts, NASA content, and authentic science experiences. Through value-based decision making and community building, intentional and independent evaluation, efficient coordination of mutually reinforcing activities, and open and continuous communication, SciAct works to maximize its reach and impact beyond what individual projects can do alone.

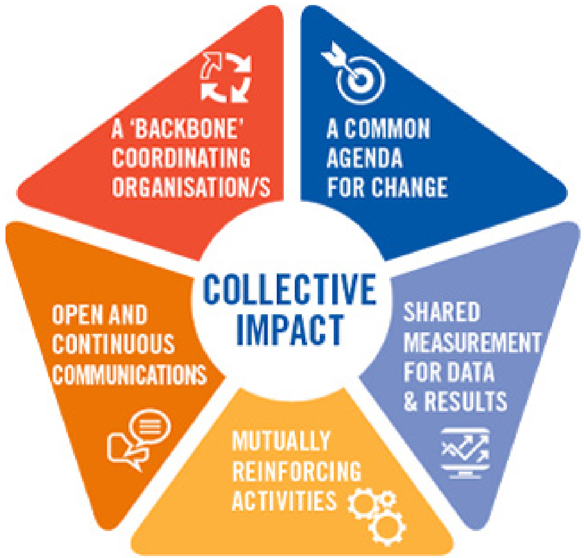

Figure 1. Depicts the key elements that organizations need for successful collective impact. **Figure credit:** **Using a Collective Impact Approach to Support Youth Pathways in Technology**, a case example by Rafi Santo, New York University (2019)

Ten SciAct teams focus primarily on Earth science, and another **two dozen teams** focus on specific audience segments while working across all or several SMD science disciplines.

Reach and Engage: Learners Across the Nation and Beyond

In 2022, the SciAct program facilitated 52 million learner interactions in the U.S.—see **Figure 2**—and about a quarter-million abroad. The program now works to bolster its already impressive reach and engagement successes through enhanced communications and social media strategies that leverage NASA's extensive networks. As one example, the SciAct communications and project teams collaborated to compile and organize a wealth of back-to-school resources for teachers in August 2022 and again in 2023. These campaigns help expose millions more potential learners and educators to NASA science learning resources.

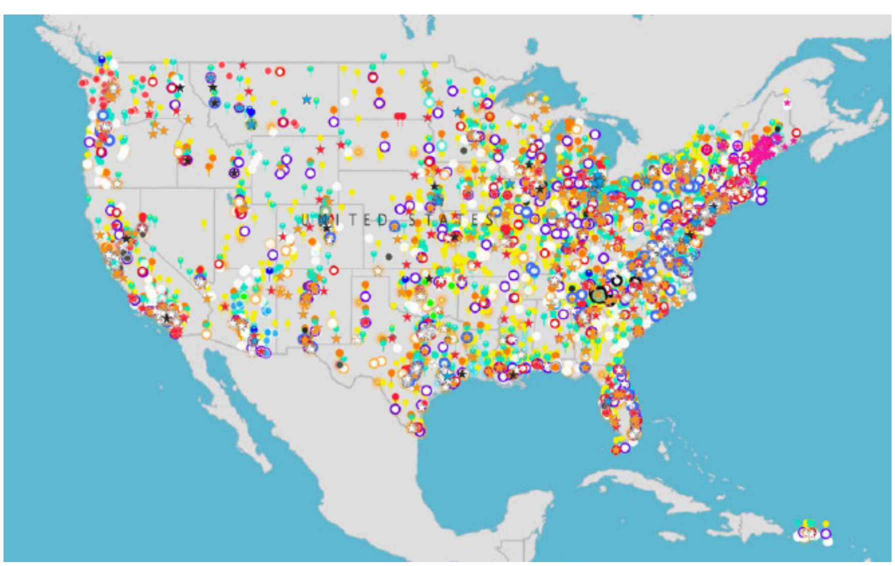

Figure 2. This map shows locations where the SciAct teams conducted various learner interactions across the lower 48 states and Puerto Rico during 2022. Explore details in the interactive **Science Activation Reach Map**. **Figure credit:** NASA Science Activation Reach Map

Leverage: 590 Partners

SciAct achieves its impressive nationwide and international reach in two primary ways:

- Teams agree on cross-collaborations within the program to leverage assets and expertise and reduce duplication of effort. This approach promotes efficiency to accomplish shared goals.
- Teams engage in strategic partnerships with additional community-based and audience-based organizations to support institutional, state, and local efforts to optimize the taxpayer investment. Each team selects and develops those relationships that help them achieve their objectives and meet the needs of specific diverse learner audiences. Since the beginning of the SciAct program in 2016, these partnerships have more than doubled, with teams reporting 590 active external partners in 2023—see **Figure 3**.

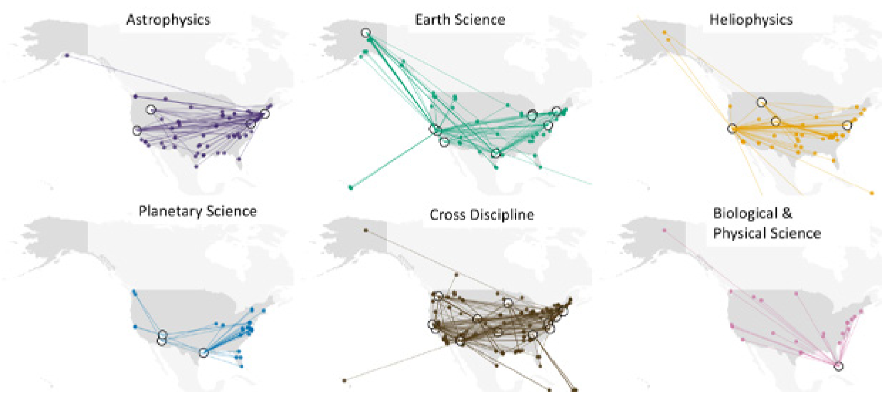

Figure 3. The SciAct teams each develop partnerships with local, regional, or national organizations that can help them advance their objectives, resulting in a robust network with extensive national reach. **Figure credit:** We Leverage Partnerships (on SciAct website)

Leveraging partnerships and collaborating both internally and externally amplifies SciAct's impact for learners across the Nation and enables connections in all 50 states, the District of Columbia, four U.S. territories, and over 150 other countries.

Inspire: Learners and Scientists

NASA and NASA-funded scientists work with SciAct, both behind the scenes and interacting directly with learners of all ages— e.g., see **Photo 2**—to share the story and adventure of NASA Science. Throughout 2023, 920 subject matter experts participated in and helped produce accurate, compelling, and innovative SciAct events and

Photo 2. Participants work on the concept of stellar spectra with guidance from a NASA subject matter expert. **Photo credit:** NASA Heliophysics Education Action Team

products—giving learners the opportunity to learn from and work hand-in-hand with real scientists in inspiring and engaging ways. You can become part of this community by **signing up** and indicating your expertise.

Innovate: Evidence-Based Learning Solutions

SciAct teams have reported more than 120 **peer-reviewed publications** documenting evidence-based solutions for reaching and motivating learners of all ages so that others can benefit from the program's lessons learned. To date, these publications have been cited over 1000 times—see **Figure 4**. The **most-cited article** was published in the *Journal of Geoscience Education* in 2019 and describes how interactive virtual field trips—a tool being developed with SciAct support—can increase learning.

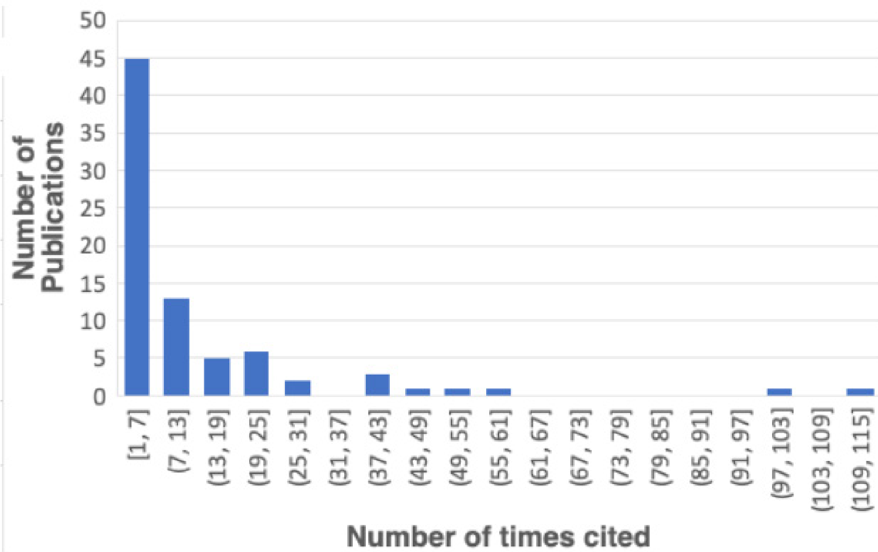

Figure 4. Histogram of citations for SciAct publications as of Oct. 31, 2023. **Figure credit:** Lin Chambers

Provide: Learning Resources

Enabled by the newly updated **NASA website**—which launched on September 28, 2023—SciAct has revalidated and revitalized the old *NASA Wavelength* collection into a new, **searchable catalog** of over 1000 learning resources. **Photo 3** shows an example of learners engaged in one such activity. In addition to individual learning resources previously available in the *Wavelength* collection, this new catalog also indexes the various types of resources that are produced by SciAct projects for specific audiences.

Photo 3. Participants look at the results of a hands-on activity, one of the many types of SciAct resources and opportunities. **Photo credit:** NASA Earth to Sky project

SciAct has also reviewed the Performance Expectations from the Next Generation Science Standards and created a **list of standards** that align to NASA Earth science. SciAct plans to index the learning resources collection to these standards in the future.

Empower: Broadening Participation

Diversity, equity, inclusion, and accessibility provide critical values that underscore SciAct's commitment to broadening participation since the program began. Over half of the SciAct portfolio focuses on broadening participation of specific groups as a primary goal, and the remaining projects work to broaden participation more generally, while also learning from the teams working with specific audiences—see **Figure 5**.

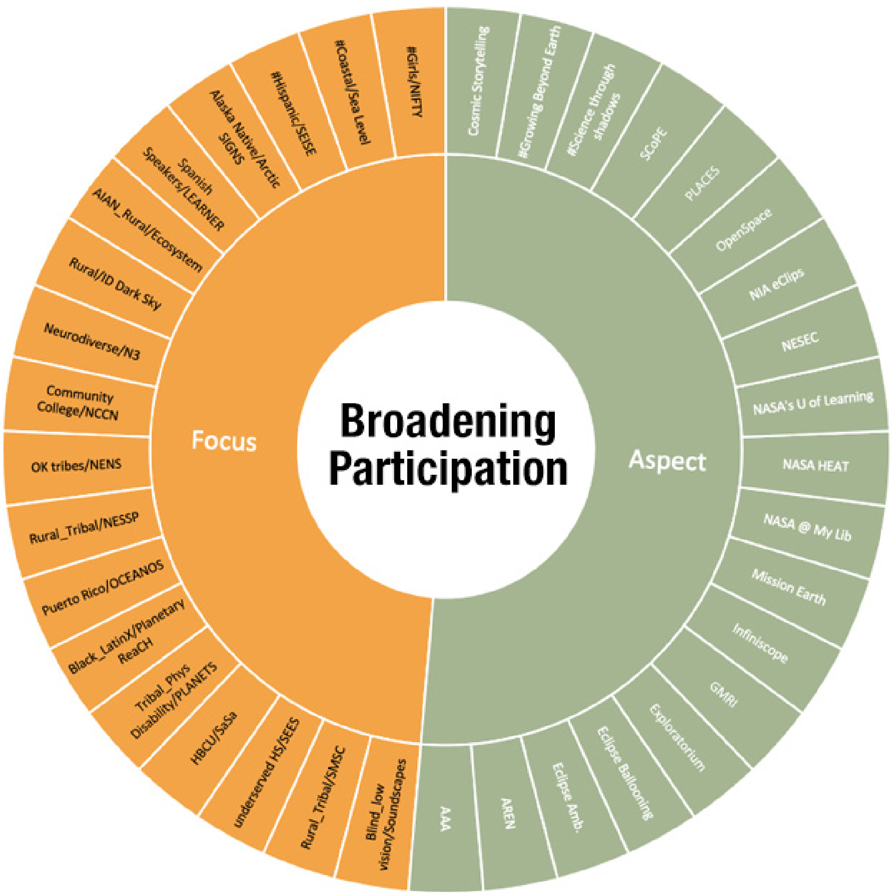

Figure 5. Since the start of 2021, more than half of the SciAct teams have focused their efforts on broadening participation by specific underserved communities. The rest of the SciAct portfolio incorporates broadening participation in some aspects of their work while otherwise focusing on science content or broader audience segments. Projects marked with # were new in mid-2022. **Editor's Note:** Acronyms for the individual SciAct activities listed on the outer ring of this Figure are not expanded. While they can easily be found online, the focus of the Figure is the middle rings, which illustrate the two primary ways all these activities work together to achieve the overall SciAct goal of broadening participation (the inner most ring). **Figure credit:** SciAct Program

SciAct aims to serve historically underrepresented groups in STEM fields by delivering activities and experiences tailored to learners of particular backgrounds and learning styles. Teams also leverage subject matter experts with diverse backgrounds and career experiences. SciAct brings **new learners** to the process of science via projects and activities specifically designed to support community college, differently-abled, immigrant, indigenous, multilingual, neurodiverse, rural, and other disadvantaged, underserved, and underrepresented communities. This approach closely aligns with the national agenda for STEM education in its priority to increase diversity, equity, and inclusion in these fields. SciAct also leverages SMD's attendance at targeted meetings and conferences to enhance the reach to these communities.

Science Activation and Earth Science

SciAct connects learners of all ages across all NASA science disciplines, including, Earth, Solar System, Space Experiments, the Sun, and the Universe. **Table 2** lists the ten **SciAct project teams** that focus primarily on Earth science.

Table 2. SciAct project teams focused primarily on Earth science.

Team Short Name	Lead Organization	Brief Description
AEROKATS/ROVER Education Network	Wayne Regional Educational Service Agency (Michigan)	Providing learners hands-on experiences with science instruments and NASA technology.
Arctic and Earth SIGNs	University of Alaska, Fairbanks	Engaging rural and indigenous youth, educators, and more in climate science.
Earth to Sky	NASA's Goddard Space Flight Center	Helping interpreters and environmental educators access and use NASA climate science.
GLOBE Mission EARTH	University of Toledo	Enhancing K–12 science, technology, education, and mathematics (STEM) curricula with hands-on NASA and GLOBE learning activities.
Learning Ecosystems Northeast	Gulf of Maine Research Institute	Helping educators create NASA-powered explorations of local climate change impacts.
NASA Earth Science Education Collaborative	The Institute for Global Environmental Strategies (IGES) in partnership with several NASA centers	Enhancing STEM teaching and learning by creating engaging, meaningful STEM experiences.
OCEANOS	NASA's Ames Research Center	Engaging Hispanic and Latino students in ocean science using NASA Earth observations.
PLACES	WestEd	Helping educators engage students in data-rich, place-based Earth science learning.
Sea Level Education, Awareness, & Literacy	NASA/Jet Propulsion Laboratory	Improving understanding of sea-level rise in historically underserved coastal communities.
SEES: Texas Space Grant Consortium	University of Texas at Austin	Increasing the number of high school students, particularly under-represented minorities, and those from under-served areas pursuing STEM college degrees.

SciAct connects learners of all ages across all NASA science disciplines, including, Earth, Solar System, Space Experiments, the Sun, and the Universe.

Conclusion

Through its intentional efforts to collaborate across projects and to broaden participation in NASA Science activities, SciAct is fully realizing **NASA's Explore Science 2020–2024 A Vision for Science Excellence** Priority 4 Strategy to "increase the diversity of thought and backgrounds represented across the entire SMD portfolio through a more inclusive environment." This article summarized the variety of means through which SciAct accomplishes this and highlighted 10 Earth-science-focused programs. Readers are encouraged to visit the **Science Activation website** and more fully explore how this program connects diverse learners of all ages with NASA science, content, and experts in ways that activate minds and promote a deeper understanding of our world. They will discover resources and opportunities to learn science and connect with SciAct teams to see how their science might be integrated into this impactful work. ■

SHADOZ Ozonesonde Network Celebrates 25 Years and 10,000 Profiles

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Anne Thompson, NASA's Goddard Space Flight Center, Emeritus/University of Maryland, Baltimore County, anne.m.thompson@nasa.gov
Debra Kollonige, NASA's Goddard Space Flight Center, Emeritus/Science Systems and Application, Inc., debra.e.kollonige@nasa.gov

Introduction

NASA's Goddard Space Flight Center's (GSFC) **Southern Hemisphere Additional OZonesondes** (SHADOZ) network, which coordinates balloon-borne ozonesonde launches from 14 tropical sites through global partnerships (see **Figure 1** and **Table**, both on page 15), has reached two milestones: 25 years of operation and the archiving of 10,000 ozone and pressure-temperature-humidity (P-T-U) datasets. The 2023 archive amassed 400 profile pairs from the 14 stations—bouncing back from reduced operations during the COVID-19 pandemic. SHADOZ data are always in high demand for trend studies, ozone assessments, development of new satellite algorithms, and model evaluations. In 2023, more than 20 publications referenced SHADOZ data and on average the SHADOZ archive has over 300,000 data user hits in a year.

The SHADOZ leadership team consists of **Ryan Stauffer** [GSFC—*SHADOZ Principal Investigator (PI)* since 2021], **Anne Thompson** [GSFC, *Emeritus—Founding SHADOZ PI*, 1998–2021], and **Debra Kollonige** [*Emeritus*—GSFC/Science Systems and Applications Inc. (SSAI)—*Data Archiver* and *Website Manager*]. Several sources provide data for SHADOZ including: GSFC, NASA's Wallops Flight Facility, NOAA's Global Monitoring Laboratory, as well as international partners—from 14 nations on five continents.

Originally proposed as a three-year project to enhance the number of ozone profiles used for satellite algorithms in an under-sampled region of the world, SHADOZ has far exceeded its original scope and transformed our view of tropical ozone chemistry and dynamics as well as operational practices throughout the entire 60-station global sonde network. This article will summarize how SHADOZ has:

- *coordinated ozonesonde launches to support more than 20 spaceborne instruments*, which have led to advances in satellite ozone retrieval algorithms and enabled detection of instrument drift—see **Figure 2** on page 16.[1]
- *built capacity at network sites*, by promoting "twinning" sponsorships—see **Figure 1** on page 15—that empower data providers through training, participation in laboratory tests of ozonesondes, and regular online meetings.
- *enabled technological advances*, by working within the **World Meteorological Organization** (WMO)/**Global Atmosphere Watch** (GAW) framework to facilitate instrument intercomparisons that have improved ozone profile data quality from 10–15% uncertainty in 1998 to ~5% uncertainty at present; and
- *contributed data leading to scientific advances*, in which SHADOZ profiles have been used to: study stratospheric and tropospheric ozone to assess impacts of climate oscillations on ozone distributions; determine sources of tropospheric and tropical tropopause layer (TTL) ozone; determine the structure of the zonal wave-one in tropospheric ozone and interactions with convection; and establish trends in TTL ozone—which provides a standard reference for satellite and model-derived estimates.

Originally proposed as a three-year project to enhance the number of ozone profiles used for satellite algorithms in an under-sampled region of the world, SHADOZ has far exceeded its original scope and transformed our view of tropical ozone chemistry and dynamics as well as operational practices...

[1] See page five of the SHADOZ 20th anniversary article referenced in footnote 2 for a description of ozonesondes.

Celebration of both its 25-year milestone and collection of its 10,000th total ozone profile in 2023 offers another opportunity for reflection on the transformative scientific contributions of the SHADOZ program. This report builds on a previous article in *The Earth Observer* to mark the 20th anniversary of SHADOZ published in 2019.[2] While this article summarizes some of the same information included in the 2019 article, the focus here is on new developments over the past five years and an assessment of the impact of a quarter-century of SHADOZ observations. The following sections review the origins and establishment of the SHADOZ network, the current status of the **SHADOZ archive**, SHADOZ leadership in advancing ozonesonde quality assurance, and recent SHADOZ discoveries through analysis of ozone trends in the lowermost stratosphere and free troposphere.

This report builds on a previous article in The Earth Observer *to mark the 20th anniversary of SHADOZ published in 2019. While this article summarizes some of the same information included in the 2019 article, the focus here is on new developments over the past five years and an assessment of the impact of a quarter-century of SHADOZ observations.*

SHADOZ Origins and History

The original aim of the SHADOZ ozonesonde network was to enhance the development of a more robust ozone profile climatology for satellite algorithm refinement. In contrast to the well-established sounding stations in mid- and polar latitudes 25 years ago, the tropics remained undersampled. Natal, Brazil (6° S, 35° W), with intermittent soundings from American Samoa and Hawaii (see Table on page 15), provided the only soundings in the 1970s and 1980s, with minimal soundings over tropical Africa or Asia. During campaigns such as **NASA's Transport and Atmospheric Chemistry Experiment-Atlantic** (TRACE-A) in 1992 and **Pacific Exploratory Mission (PEM)-Tropics-A** in 1996, sondes operated in the tropics and subtropics, complementing aircraft measurements by adding profile data above flight altitudes. The existing infrastructure for resuming soundings, including facilities, launch gas, and personnel, was already in place in these regions. In addition, Japanese researchers had established partnerships with agencies in Malaysia and Indonesia, providing additional motivation for NASA to establish SHADOZ.

The SHADOZ network design concept was innovative in aiming to:

- supply *existing* stations with additional ozonesonde expendables (approximately $1000/launch) to achieve a frequency of approximately four launches per month;
- collect *all* sonde data from a given station and distribute it through a simple-format website at GSFC without then-standard passwords or account setup;
- select stations to cover the entire tropical zone;
- establish ongoing collaborations with local entities (e.g., meteorological services, space agencies, universities) and sponsors (e.g., Japanese and European agencies) to leverage resources for sustaining long-term operations; and
- provide operational training where needed, and collaborate with in-country data providers in publication of results.

Current Network Status and Data Archive

Figure 1 illustrates the 14 SHADOZ stations with at least 10 years of operation, and the accompanying Table provides information on sponsoring organizations and the number of available ozone profiles as of October 2023. Note that the SHADOZ data archive includes profiles from three stations that only launched sondes for several years: Tahiti (1998–1999); Malindi, in coastal Kenya (1999–2006); Cotonou, Benin (2005–2007). Four stations are located in the subtropics: Hanoi and Hilo in the north, and Irene and La Réunion Island in the south—refer to Figure 1 for their respective locations. Additionally, 10 of the SHADOZ stations feature nearby or colocated, ground-based, total-column ozone instruments, such as the **Brewer spectrophotometer**, **Dobson spectrophotometer**, and **Système D'Analyse par Observations Zénithales (SAOZ) spectrometer**, for satellite calibration purposes.

[2] 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].

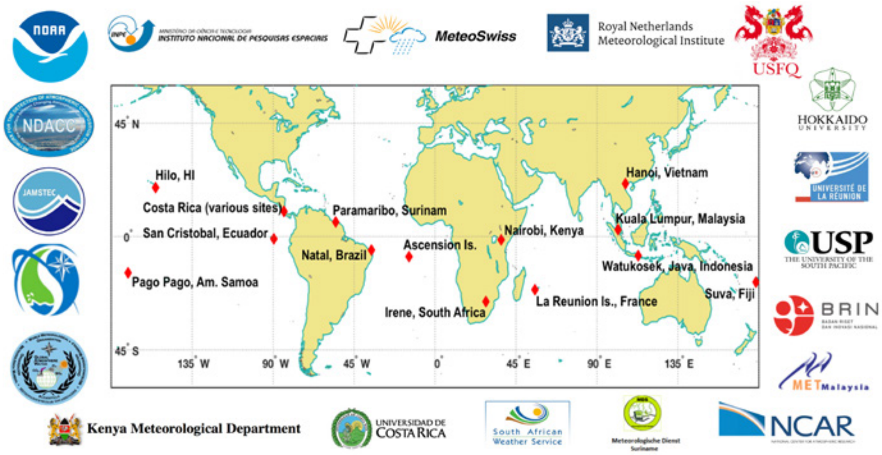

Figure 1. Map of SHADOZ stations where more than 10 years of data have been collected—from 1998–2023. Periods of operations and total profile numbers are listed in the accompanying **Table**. **Image credit:** Debra Kollonige/GSFC/SSAI

Table. SHADOZ stations and partners with at least 10 years of data, with stations beginning between 1998–1999 except for Costa Rica (2005) and Hanoi (2004).

Station [latitude, longitude]	Partner Organization	Years Operational	Number of Profiles Obtained*
Hanoi, Vietnam [21.02° N, 105.81° E]	Vietnam Meteorological and Hydrological Administration and Japan Agency for Marine-Earth Science and Technology (JAMSTEC)	2004–Present	403
Hilo, Hawaii [19.72° N, 155.05° W]	Mauna Loa Observatory (NOAA/GML)	1998–Present	1279
San Pedro, Costa Rica [9.94° N, 84.04° W]	Universidad de Costa Rica	2005–Present	705
Paramaribo, Surinam [5.81° N, 55.21° W]	Meteorological Service of Surinam and KNMI	1999–Present	908
Kuala Lumpur, Malaysia [2.72° N, 101.70° E]	Malaysian Meteorological Department	1998–2010; 2012–Present	527
San Cristóbal, Galapagos, Ecuador [0.90° S, 89.61° W]	Universidad San Francisco de Quito (USFQ)	1998–2008; 2012–2016; 2021–Present	508
Nairobi, Kenya [1.30° S, 36.76° E]	Kenyan Meteorological Dept. and MéteoSwiss	1998–Present	1020
Natal, Brazil [5.84° S, 35.21° W]	Instituto Nacional de Pesquisas Espaciais (INPE) [Brazilian Space Agency], GSFC, and NASA's Wallops Flight Facility	1998–2011; 2013–Present	763
Watukosek, Java, Indonesia [7.57° S, 112.68° E]	Badan Riset dan Inovasi Nasional (BRIN) [National Research and Innovation Agency]	1998–2013; 2021–2022	372
Ascension Island [7.97° S, 14.40° W]	U.S. Space Force and GSFC	1998–2010; 2016–Present	876
Pago Pago, American Samoa [14.33° S, 170.71° W]	American Samoa Observatory (NOAA/GML)	1998–Present	915
Suva, Fiji [18.15° S, 178.45° E]	University of the South Pacific and NOAA/GML	1998–Present	499
La Réunion, France [20.89° S, 55.53° E]	Université La Réunion, Météo-France, and Centre National de la Recherche Scientifique (CNRS)	1998–Present	842
Irene, South Africa [25.91° S, 28.21° E]	South African Weather Service	1998–2008; 2012–Present	428

* These values represent the total number of profiles archived from each station as of October 2023.

In addition to the sustained support of SHADOZ operations, the popularity and growing applications of the data have contributed to the network reaching its milestone 10,000th profile—see **Figure 3**. In any given year, SHADOZ profiles average 350–400 profiles per year and represent about 20% of the data from all long-term ozonesonde stations across the globe. Furthermore, SHADOZ samples over a region that is equivalent to about 35–40% of Earth's surface. The 2023 totals—shown in Figure 3—suggest that SHADOZ has fully rebounded from a downturn in data collection associated with COVID-19 shutdowns.[3]

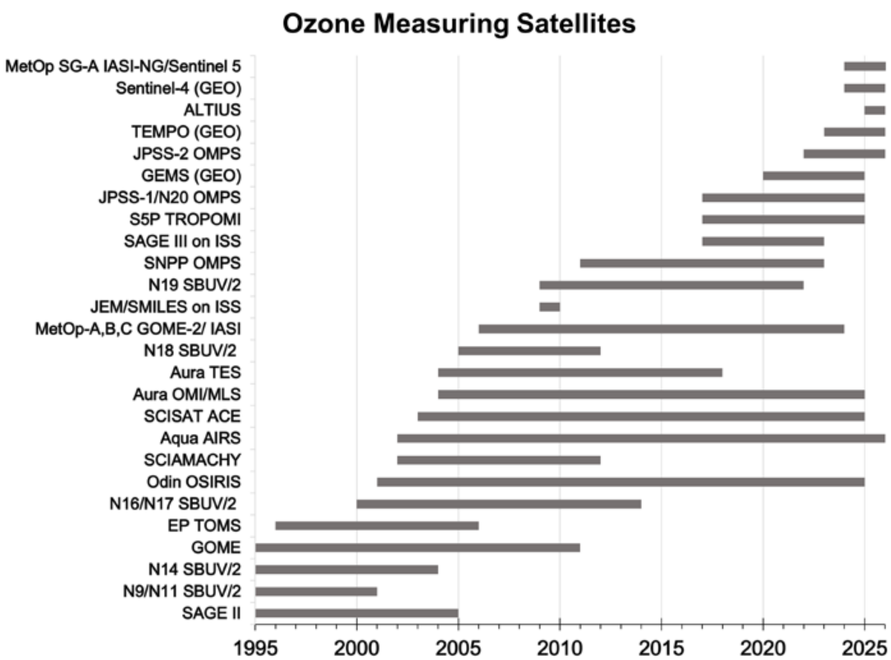

Figure 2. Timeline of ozone-measuring satellites that have used SHADOZ ozonesonde data for algorithm development and validation since 1995. **Editor's Note:** Acronyms for mission and instrument names used on the y-axis of the graph are well known—and thus not expanded here. (N is short for NOAA.) **Image credit:** Debra Kollonige

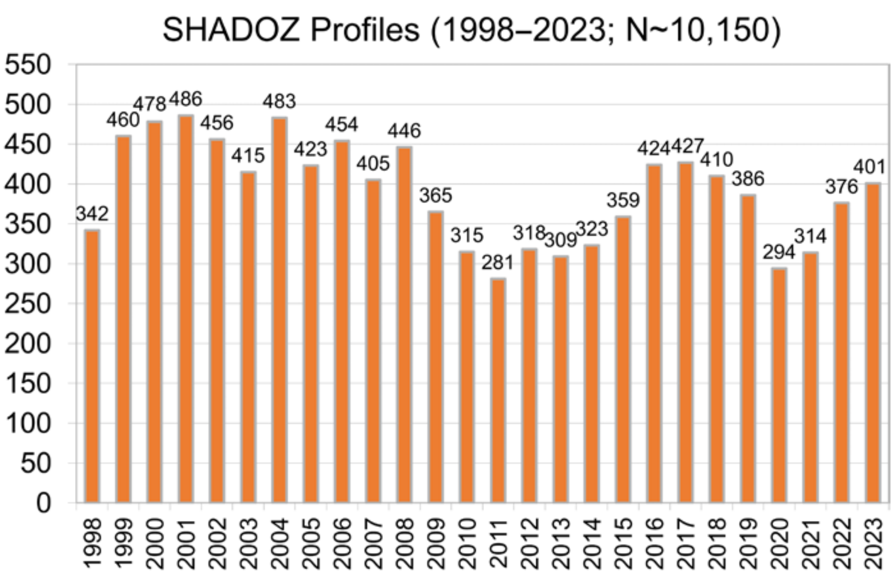

Figure 3. Total number of archived SHADOZ ozonesonde profiles for each year from 1998–2023. Note that 2023 is an estimate for the full year. **Image credit:** Debra Kollonige

Technological Advances: SHADOZ Leads Data Quality Assurance Activities

With a few exceptions, the ozonesonde instrument's basic construction has remained relatively constant since its invention in the 1960s. Generally, each ozonesonde is

[3] To learn more, see **NASA's SHADOZ Team Makes Advances in 2021 Despite the Pandemic** in the May–June 2021 issue of *The Earth Observer* {**Volume 33**, **Issue 3**, pp. 12–17, 24].

considered expendable and is "launched and lost," meaning special care must be taken to characterize the instrument's performance in the lab prior to launch. Much has been learned about the mechanical and chemical properties of the ozonesonde in the past few decades, which has led to ever-increasing data quality and accuracy through international cooperative efforts often spearheaded by the GSFC SHADOZ Team.

SHADOZ Data Accuracy: JOSIE and ASOPOS

The high accuracy and reliability of the SHADOZ (and global network) high-vertical-resolution ozone profiles—and thus their prominence in scientific studies—is a result of the GSFC SHADOZ team's leading role in ozonesonde data quality assurance. For the past ~25 years, a series of **Jülich Ozonesonde Intercomparison Experiments** (JOSIE) have been held at Forschungszentrum Jülich (FZJ), Germany, including the GSFC co-led 2017 JOSIE–SHADOZ that was discussed at length in the 2019 article referenced in footnote 2. By carefully controlling temperature and ozone amount in the FZJ World Calibration Centre for Ozonesondes (WCCOS) test chamber, the JOSIE experiments evaluate various ozonesonde manufacturers, ozone sensing solution types, operating procedures, and the overall performance of the ozonesondes under simulated flight conditions. Analysis of JOSIE–SHADOZ 2017 and field experiment results led to the prescription of standard operating procedures (SOPs) by the Assessment of Standard Operating Procedures for OzoneSondes (ASOPOS and ASOPOS 2.0) as described in the landmark **August 2021 ASOPOS 2.0 Report** that are then implemented into the global network. The JOSIE–SHADOZ results were published first in a 2019 paper in **Bulletin of the American Meteorological Society**, on which Anne Thompson was lead author. They showed that, on average, total column ozone integrated from the ozonesondes matched the WCCOS ozone reference within ±3%. The most recent achievement from SHADOZ and the global ozonesonde network is the traceability of every ozonesonde profile to the world standard ozone reference at the WCCOS. Thanks to the ASOPOS-derived SOPs, ozonesonde data accuracy has seen a remarkable improvement from decades ago when ozonesonde biases of 10% or more were common.

Stability of SHADOZ Ozone Time Series

Because each ozonesonde is launched and lost, and procedures or instrument manufacturers may change over time, ASOPOS recommends tracking data quality according to the practices that SHADOZ developed. This means carrying out routine comparisons of ozonesonde measurements against satellite and colocated, ground-based, total column ozone data, including the Aura satellite's Microwave Limb Sounder (MLS) stratospheric profiles, and a series of satellites carrying ultraviolet/visible (UV/VIS) instruments measuring ozone profiles and column ozone amounts. While the ozonesondes have historically been used to validate the satellite data (not the other way around), the best-calibrated satellite ozone instruments have matured to the point where they provide a useful reference to assess the long-term stability of ozonesonde network data. An example time series of comparisons among the ozonesonde data at the La Réunion SHADOZ station and various satellite sensors since the launch of Aura in 2004 is shown in **Figure 4** on page 18. The La Réunion profiles (both in the stratosphere and the integrated total column ozone) are exceptionally stable relative to the satellite data, with comparisons varying by just a few percent over the last two decades.

While the ozonesondes have historically been used to validate the satellite data (not the other way around), the best-calibrated satellite ozone instruments have matured to the point where they provide a useful reference to assess the long-term stability of ozonesonde network data.

Even Better Data on the Way: Future Data Reprocessing

The publication of SHADOZ Version 6 (V06) data and associated manuscripts in the late-2010s marked a milestone for tropical ozonesonde data quality. Furthermore, the SHADOZ team anticipates using the results generated from the various JOSIE campaigns and laboratory experiments to eventually produce new V07 data. The two major changes to data processing between V06 and V07 will be:

- *a correction for a sudden reduction in the efficiency of the ozonesonde pump for one of the two manufacturers*, which has caused a recent stratospheric low ozone bias, documented in three recently published papers; and
- *accounting for the time-response delay of the ozonesonde instrument sensor, making the ozone profile data more accurate in the tropopause region*, where ozone amounts quickly change with altitude by up to an order of magnitude.

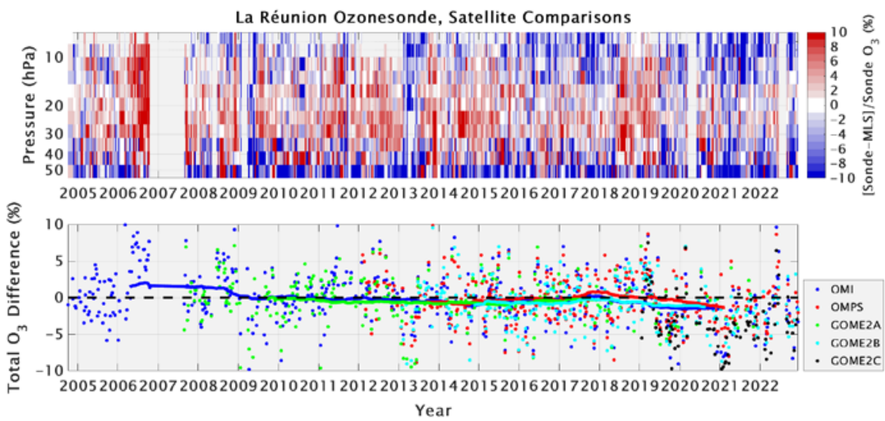

Figure 4. Coincident ozonesonde and satellite comparisons in percent difference for the La Réunion station. [*Top*] Time series comparisons of all ozonesonde and Aura/Microwave Limb Sounder (MLS) ozone profiles ([Sonde-MLS/Sonde]). Red or blue colors indicate where the ozonesonde's ozone concentration is greater or less than MLS. [*Bottom*] Ozonesonde and satellite total column ozone (TCO) comparisons in percent difference [Sonde–Satellite/Sonde] for Aura/Ozone Monitoring Instrument (OMI: blue); Suomi National Polar-orbiting Partnership/Ozone Mapping and Profiler Suite (OMPS: red); European Operational Meteorological (MetOp) Satellite/Global Ozone Monitoring Experiment–2 (GOME-2A: green, GOME-2B: cyan, and GOME-2C: black). The lines corresponding to each TCO satellite instrument indicate 100-ozonesonde centered, moving averages. (**NOTE:** Values for the first and last 50 comparisons are not plotted for the moving averages.) **Image credit:** Ryan Stauffer/GSFC

Recent SHADOZ Scientific Accomplishments

Progress made toward higher-quality ozonesonde data and the release of reprocessed V06 profiles drove many of SHADOZ' recent scientific accomplishments. Namely, SHADOZ ozone profiles were sufficiently accurate to calculate reliable trends over a more than two-decade period and serve as the gold-standard for ground- and satellite-based ozone instrument intercomparisons.

25 Years of Definitive Ozone Profile Trends

The demonstration of the improved accuracy of SHADOZ V06 data motivated a re-examination of tropical ozone trends. SHADOZ trends of free-tropospheric (FT) ozone, which is defined as 5–15 km (~3–9 mi), and lowermost stratospheric (LMS) ozone, which is defined as 15–20 km (~9–12 mi), were calculated from 1998–2019. The results of this research were published in a landmark 2021 paper in **Journal of Geophysical Research (JGR): Atmospheres** with Anne Thompson as first author. The analysis identified both common and distinct patterns across five well-distributed tropical SHADOZ stations (combining records from three of them). Among the findings:

- FT ozone trends were seasonally and longitudinally varying, ranging from about +1 to +4% per decade across the sites on an annual basis, but up to +20% per decade in certain months;
- All stations exhibited peak FT ozone trends in the first half of the year—generally coinciding with the convectively active, typically low ozone times of year; however, FT ozone trends were generally weak thereafter; and
- Most stations exhibited significant negative LMS ozone trends in the second half of the year during which positive trends in tropopause height were discovered. Trends computed in tropopause height-relative coordinates showed that this negative trend disappeared. This result signals an "artifact" negative trend in LMS ozone and a likely manifestation of climate change, instead of chemical loss of ozone.

This article provides an update to the 1998–2019 SHADOZ trends study (summarized above) to determine the robustness of the LMS and tropopause height trends with three more years of profiles (1998–2022). **Figure 5** depicts monthly trend output from the GSFC Multiple Linear Regression (MLR) model for the five stations: San Cristóbal and Paramaribo (SC-Para), Natal and Ascension Island (Nat–Asc), Nairobi, Kuala Lumpur and Watukosek (KL–Java), and Samoa.

As with the original study, there is a strong anticorrelation among ozone trends at 15–20 km (9–12 mi) (Figure 5, *top*) and the 380 K potential temperature (θ) surface (Figure 5, *middle*) trends. Referencing the altitude coordinates to the tropopause height (Figure 5, *bottom*), the LMS ozone trends disappear, and the conclusions of the 2021 study remain robust when adding three years of additional SHADOZ data and computing 25 years of trends. Additional follow-on work is currently underway to link the early part of the year positive FT trends described above with a decrease in convective activity over the Kuala Lumpur and Watukosek stations.

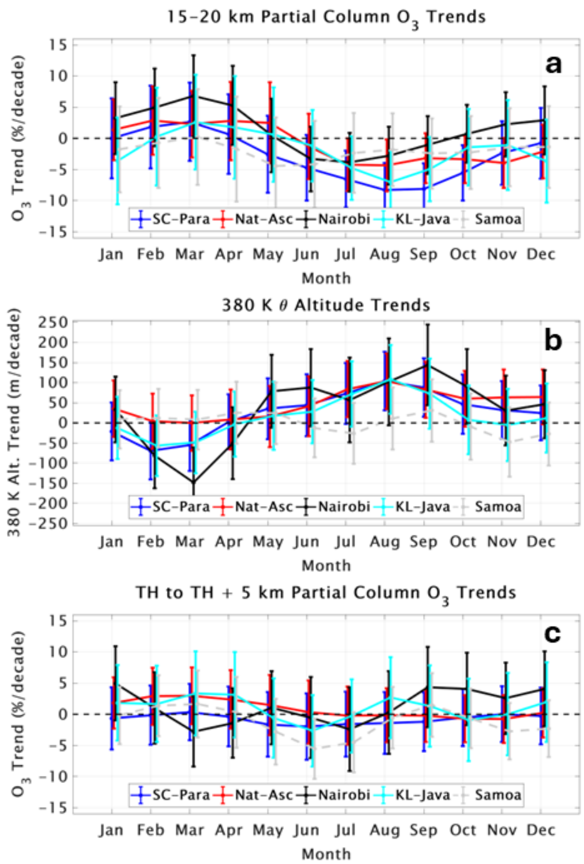

Figure 5. GSFC Multiple Linear Regression (MLR) model trends for lowermost stratosphere (LMS; 15–20 km, or 9–12 mi) ozone in percent-per-decade [*top*], altitude of the 380 K potential temperature (θ) surface—commonly used to define tropopause height in the tropics—in meters-per-decade [*middle*], and ozone trends recomputed in tropopause-relative height coordinates for the tropopause height (TH) to 5 km (3 mi) above the tropopause height above [*bottom*]. **Image credit:** Ryan Stauffer

Tropospheric Ozone Trends and Assessment Report

The extensive SHADOZ record and highly-accurate ozone data along with the network of *in-situ* tropical ozone profiles played a key role in the International Global Atmospheric Chemistry (IGAC) community-sponsored **Tropospheric Ozone Assessment Report**, Phase I (**TOAR-I**) from 2014–2019, and the currently ongoing Phase II (**TOAR-II)** which ends in 2024. The follow-on assessment seeks to understand the distribution, recent trends, future projections of tropospheric ozone, and the harmful effects of tropospheric ozone on crop production and human health. The SHADOZ team participates in three of the TOAR-II Working Groups: **Harmonization and Evaluation of Ground Based Instruments for Free Tropospheric Ozone Measurements** (HEGIFTOM), the **Ozone and Precursors in the Tropics** (OPT), and the **Ozone over the Oceans**.

SHADOZ profiles are the gold standard and thus are used in TOAR-II to evaluate other sources of ozone data such as profiles from the **In-service Aircraft for a Global Observing System** (IAGOS) program and ground-based measurements from Brewer and Dobson spectrophotometers, Fourier transform infrared (FTIR) instruments, and lidar. The SHADOZ trends for the FT produce results by which other instrument platforms and model simulations will be judged. **Figure 6** on page 20 provides an example of ozone time series, including the SHADOZ Kuala Lumpur (KL) and Watukosek (Java) stations, and IAGOS from the same Malaysia + Indonesia region. These data display generally good agreement between SHADOZ and IAGOS over tropical Southeast Asia. Note that Figure 6 also includes pre-SHADOZ data from KL, extending the available data set for ozone trends calculations and comparisons with other sources of ozone data, including from satellites over several decades.

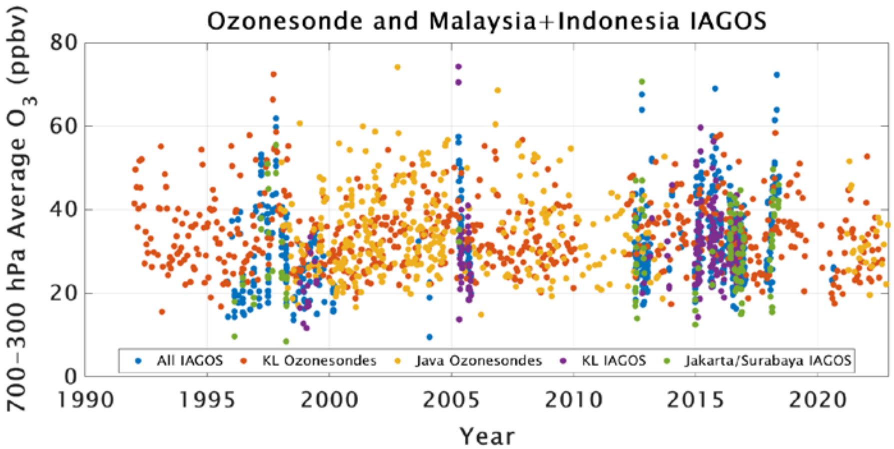

Figure 6. SHADOZ and IAGOS time series of average ozone amounts in parts-per-billion by volume (ppbv) in the 700–300 hPa pressure layer (~3–10 km or ~2–6 mi altitude). Values for all IAGOS aircraft profiles are shown in blue, with IAGOS profiles above Kuala Lumpur (purple) and Jakarta/Surabaya (green) highlighted. The ozonesonde data for KL, including pre-SHADOZ data dating back to 1992, are shown in orange. Watukosek (Java) ozonesonde data are shown in yellow. **Image credit:** Ryan Stauffer

Conclusion and Looking Ahead

The SHADOZ ozonesonde network has amassed a remarkable 25-year data set from its currently 14 active stations, with the milestone 10,000th ozonesonde profile archived in 2023. The GSFC SHADOZ team continues to lead the way on ozone science and data quality assurance for the entire global network of ~60 stations. The success of the network is due, in no small part, to the prolific use of the high-quality data by hundreds of scientists across the globe, the dedication of local institutions and station operators, and the unwavering support for the data collection and GSFC archive implementation from NASA Headquarters.

SHADOZ has innovated from the start, with the concept of leveraged resources to sustain operations; open access and simple formats; engage operators in standardizing ozonesonde best practices; develop quality indicators; and host regular online meetings with station managers, technicians, and data archivers.

SHADOZ will continue to push the boundaries of what is possible regarding the accuracy from ozonesonde data. With the eventual reprocessing and publication of V07 data, the user community can expect new science and more advanced satellite products derived using SHADOZ in the near-future. ■

Acknowledgments

The authors of this article are grateful for the steady support received from NASA's Science Mission Directorate and, in particular, the support of the Upper Atmosphere Research Program (UARP) managers at NASA Headquarters: **Michael Kurylo**, [1998–2007] and **Kenneth Jucks**, [2008–present].

Summary of the Fifty-Second U.S.–Japan ASTER Science Team Meeting

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Introduction

The **Advanced Spaceborne Thermal Emission and Reflection Radiometer** (ASTER) Science Team (ST) organized a three-day workshop that took place September 11–13, 2023, at the offices of Japan Space Systems (JSS) in Tokyo. Over 40 people from Japan and the U.S. participated in the in-person meeting—some of whom are shown in the **Photo** below. U.S. participants included members from NASA/Jet Propulsion Laboratory (JPL), NASA's **Land Processes Distributed Active Archive Center** (LPDAAC), NASA's Goddard Space Flight Center (GSFC), University of Arizona (UA), Grace Consulting (GC), and University of Pittsburgh (Pitt). Japanese members included representatives from JSS, Ibaraki University (IU), Nagoya University (NU), University of Tokyo (UT), Geologic Survey of Japan (GSJ), National Institute of Advanced Industrial Science and Technology (AIST), University of Tsukuba (UTs), and Remote Sensing Technology Center of Japan (RESTEC).

The meeting objectives focused on discussing impacts of the 50% budget reductions to the **Terra** mission (including ASTER) that have been proposed in the NASA Budget for Fiscal Years (FY) 2024–26; revised spacecraft management protocols by the Flight Operations Team;[1] data acquisition status; data calibration and validation; data distribution; status of Level-1 processing interruption; applications; and end-of-mission plans. After summarizing the opening plenary presentations, the remainder of this article provides highlights from meetings of the various ASTER working groups and the closing plenary session.

Opening Plenary Session

Yasushi Yamaguchi [NU] and **Michael Abrams** [JPL—*ASTER ST Leaders* from Japan and the U.S., respectively] welcomed participants and reviewed the agenda for the opening plenary and the schedule for the week's working groups.

Akira Tsuneto [AIST—*Vice President*], whose office is responsible for the ASTER project, presented a special welcome. As the former Director of Space Industry Office in the Japan Ministry of Economy, Trade and Industry (METI), he was responsible for making ASTER data free to all users.

Michael Abrams [JPL] presented **Jason Hendrickson's** [GSFC] slides on the operations status of NASA's Terra

[1] To learn more about NASA's Flight Operations, see **Earth Science Mission Operations, Part I: Flight Operations—Orchestrating NASA's Fleet of Earth Observing Satellites** in the March–April 2016 issue of *The Earth Observer* [**Volume 28**, **Issue 2**, pp. 4–13].

Photo. Some of the attendees at the fifty-second ASTER STM. **Photo credit:** Mako Komoda, JSS platform—which has changed significantly since the last meeting. The Earth Science Mission Operations (ESMO) Flight Operations Team began implementing "Lights Out Operation," reducing staff from 24/7 coverage and eliminating the night shift. These changes resulted in a small increase in data gaps and delayed anomaly response. In early 2023 Terra lost two of its 24 solar array shunts. Full power capability remains—however, there is only one spare shunt remaining. Those issues notwithstanding, Terra remains healthy after more than 23 years of operation.

Chris Torbert [LPDAAC] presented ASTER product distribution statistics. The **ASTER Global Digital Elevation Model** (DEM) continues to be the most ordered product. Torbert discussed the **ASTER Preservation Content Specification** for the end-of-mission archiving. There is a **NASA document** that describes the desired content of this archive. As described by the ST at the last meeting, most ASTER data products will be created as real files and placed in a searchable and orderable archive, accessed through NASA's **Earthdata tool**, where mission preservation documents for other instruments (e.g., **HIRDLS**, **ICESat/GLAS**, **TOMS**) can be found.

Michael Abrams [JPL] presented highlights of science results based on ASTER data—including the 2023 Earth Science Senior Review.[2] Terra presented its report to NASA Headquarters, but as of this meeting, the response is still pending. However, as stated earlier, a three-year budget reduction of 50% is anticipated.[3]

Hitomi Inada [JSS] presented the status of the ASTER instrument. Although many of the monitored components [e.g., visible-near-infrared (VNIR) pointing motor] have exceeded their original useful life in orbit, they show no signs of decreases in performance. All temperature and current telemetry trends remain straight lines.

Tetsushi Tachikawa [JSS] summarized the status of ASTER observations since the beginning of the mission. He reported that all of the global observation programs are functioning normally, acquiring data as planned. The change of the orbit repeat after the October 2022 constellation exit maneuver[4] has been accommodated in the ASTER scheduler.

[2] Every two-to-three years, NASA HQ conducts a review of the operational Earth Science missions to assess their performance and viability for continuing.

[3] UPDATE: Since this meeting, the **results of the Senior Review** were released—Terra is discussed on page 16 of the linked report. Also see page 3 of "The Editor's Corner" of this issue to learn more about Senior Review results.

[4] To learn more about Terra's drifting orbit and its orbit lowering maneuver, see **NASA Holds Discussions about the Future of the EOS Flagship Missions** in the January–February 2023 issue of *The Earth Observer* [**Volume 35**, **Issue 1**, pp. 13–17].

Simon Hook [JPL] described the status of the multispectral thermal infrared (TIR) instrument on the **ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station** (ECOSTRESS) as well as NASA's future **Surface Biology and Geology** (SBG) mission, which is part of the planned **Earth System Observatory**.

Applications Working Group

The applications session offered a sample of the variety of applications that make use of data from ASTER, see examples below. **Miyuki Muto** [IU] shared her work to estimate the volume of waste in 19 landfills in 11 countries through analysis of ASTER DEM data over the past 20 years. Analysis of data from a site in India showed that the volume of waste increased four-fold over 20 years—see **Figure 1**. All the other monitored sites showed similar large increases in waste volume.

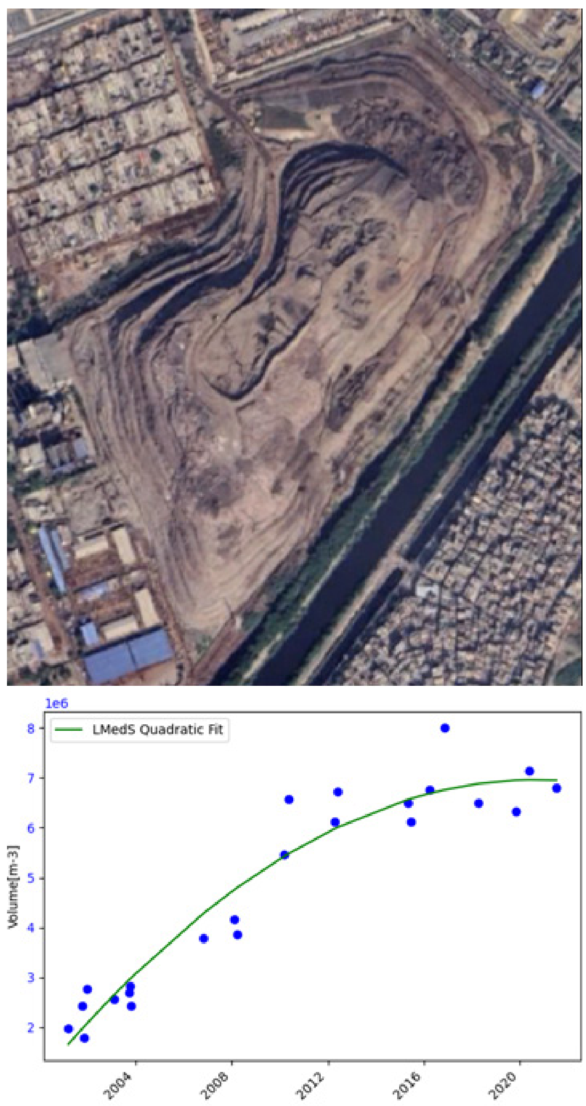

Figure 1. Google Earth Image of landfill in India [*top*] and temporal changes in volume from 2001 to 2021 [*bottom*]. **Figure credit:** Miyuki Muto and Hideyuki Tonooka, IU

Michael Ramsey [Pitt] discussed detecting volcanic eruption precursors using the entire ASTER TIR archive for six selected volcanoes: Etna, Fuego, Kliuchevskoi, Lascar, Vulcano, and Popocatepetl—four of these are shown in **Figure 2**. He and his students developed statistical methods to detect both low- and high-temperature anomalies. The team performed a *cluster analysis* on four volcanoes. By calculating and plotting heat flux versus mean temperature-above-background versus maximum temperature-above-background, clusters for eruption styles can be identified—see Figure 2. These results offer potential applicability to other volcanoes.

Calibration/Validation Working Group

This working group monitors the radiometric performance of ASTER's VNIR and TIR instruments. The team performs calibration and validation of these instruments by analysis of onboard calibration lamps or blackbody, as well as measurements of pseudo-invariant ground targets during field campaigns. No changes in instrument performance were found based on validation activities during the past year. The radiometric calibration coefficients will remain unchanged for the foreseeable future.

Temperature–Emissivity Working Group

The Temperature–Emissivity Working Group focuses on ASTER's kinetic temperature and emissivity (T–E) products and their applications, including monitoring instrument performance and calibration. They also review the status of the nighttime TIR global map program. *In situ* measurement campaigns in Japan and the U.S. use lakes and dry lake beds for ground-based calibration campaigns. Recent campaign results indicate that the TIR instrument perform within required calibration limits—see **Figure 3** on page 24.The team also noted the successful completion of the **Visible Infrared Imaging Radiometer Suite** (VIIRS)[5]–ASTER 375-m (~1230-ft) near-real-time land-surface temperature algorithm

[5] VIIRS flies on the Suomi National Polar-orbiting Partnership (Suomi NPP) as well as on NOAA-20 and -21.

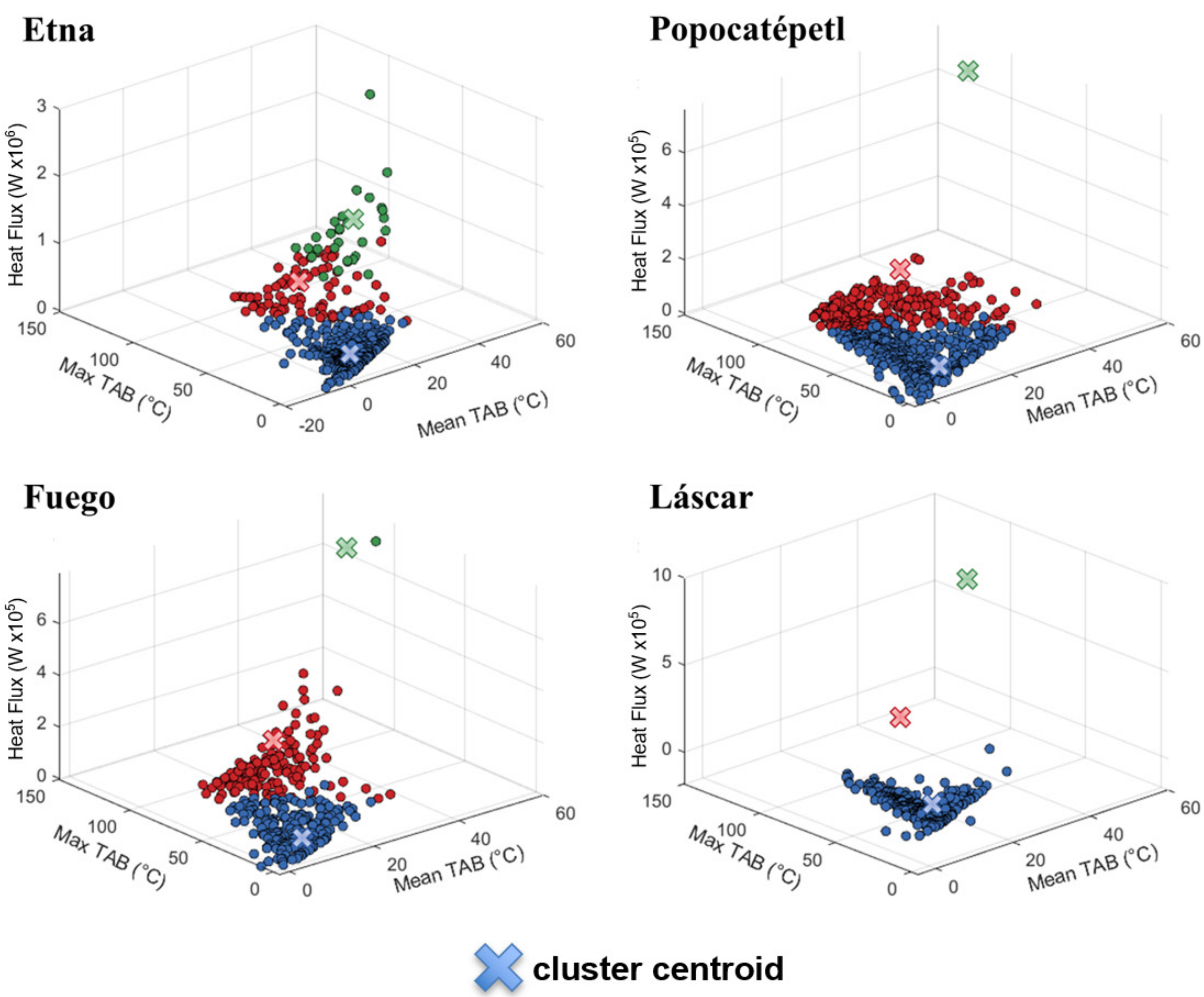

Figure 2. Three-dimensional plots show heat flux and temperature plots (further explained in the text) for hundreds of ASTER TIR scenes for four volcanoes, revealing differences related to eruptive styles. The lower cluster (*blue*) indicated fumarole and passive degassing; the medium cluster (*red*) correlated with domes and explosive and small lava flows; and the high clusters (*green*) correlated with large lava flows. **Figure credit:** Michael Ramsey/Pitt

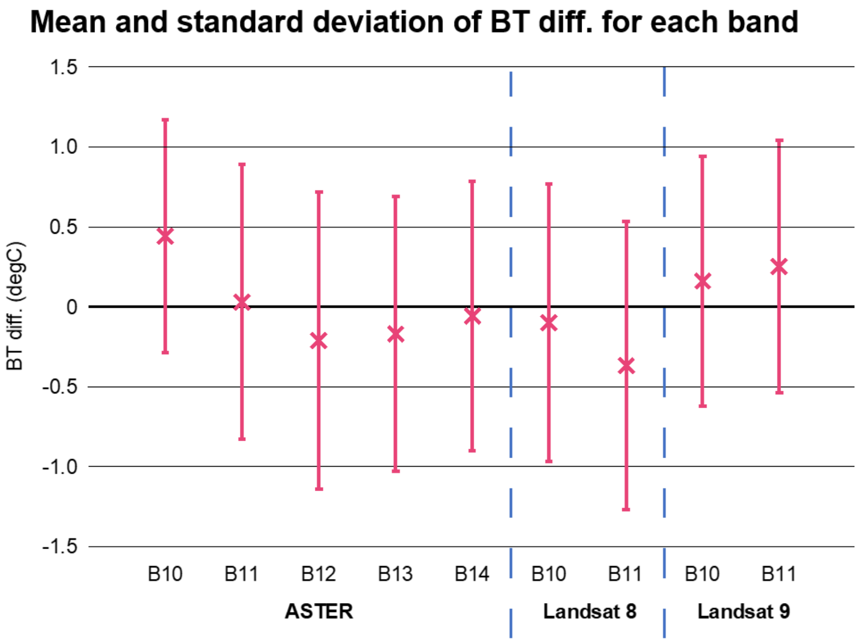

Figure 3. ASTER and Landsat 8 and 9 data provide a way to compare the satellite-derived temperature and lake surface measured temperature. ASTER mean difference for all five bands is less than 0.5 °C (~0.9 °F). On the Y axis, BT stands for Brightness Temperature. **Figure credit:** Remote Sensing Technology Center of Japan/ Soushi Kato

using ASTER emissivity for corrections. Review of the thermal global mapping acquisition program indicated that it was proceeding as planned with no changes needed.

Operations and Mission Planning Working Group

The Operations and Mission Planning working group oversees and reviews the acquisition programs executed by the ASTER scheduler. The working group schedules ASTER data acquisitions daily to accommodate ASTER's average 8% duty cycle. An automated program selects 600–700 daily scenes from the more than 3000 in the request archive.

Tetsushi Tachikawa [JSS] reviewed the status of acquisition scheduling. Urgent observations receive the highest priority and can be scheduled close to acquisition time. Approximately 70 scenes are programmed per month—with over 95% acquisition success. By contrast, global mapping data acquisitions receive the lowest priority and fill in the scenes for the daily quota. The objective is for ASTER to acquire at least one cloud-free image for every place on Earth. Due to persistent cloud cover, success is typically ~85%. The group restarts the program after several years, with the next scheduled restart in October 2024. The thermal group submits aerial requirements to acquire global nighttime coverage with the thermal bands, which will continue as scheduled. There are also acquisition programs that focus on islands, volcanoes, glaciers, and cloudy areas. The global volcano image acquisition program will continue with no change to the observation parameters. Acquisition of images of islands and over cloudy areas will also continue in current form. The global glacier acquisition program will be modified to change the VNIR gain settings to optimize images over snow and ice.

Chris Torbert [LPDAAC] reported that software fixes were ongoing for the (currently non-functional) expedited data processing at the LPDAAC.

Closing Plenary Session

Each working group chairperson summarized the presentations, discussions, and recommendations that occurred during each session. Consensus holds the ASTER instrument is operating normally, with no indications of any component failures. The backlog of unprocessed scenes resulting from the 2022 constellation exit maneuver impact on production software should clear by early October 2023. The closing highlighted the impact of the 50% budget reduction on the Flight Operation Team at GSFC with only a small increase in lost data (1–2%) due to the absence of operators to attempt immediate recovery.

Conclusion

The fifty-second ASTER ST Meeting successfully covered all of the critical issues introduced during the opening plenary session. Working groups updated instrument scheduling, instrument performance, archiving plans, and new applications. The plan is for the 2024 meeting to take place at the same venue in Tokyo. ■

Preparing for Launch and Assessing User Readiness: The 2023 PACE Applications Workshop

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Introduction

The **Plankton, Aerosol, Cloud, ocean Ecosystem** (PACE) mission represents one of NASA's next great investments in Earth Science, continuing the agency's legacy of over 40 years of satellite ocean color measurements. Launched on February 8, 2024, at 1:33 AM EST, PACE will advance our Earth observing and monitoring capabilities through hyperspectral imaging and multi-angle polarimetry of the ocean, atmosphere, and land ecosystems. To ensure the PACE mission and the anticipated data products meet the needs and objectives of applied-user and stakeholder communities, NASA's **PACE Applications Program** aims to build partnerships between data product developers, data distributors, and data users. Effective scientific communication, stakeholder engagement, and transdisciplinary research coproduction or *codesign* (e.g., designing and conducting research with those who will ultimately use the research output) are crucial elements in increasing the understanding of PACE capabilities and, in turn, broadening the practical applications and societal benefits of future PACE data.

The PACE Applications Workshop, hosted by the NASA Earth Science Applications Program since 2020, provides a forum for community as part of the PACE Applications activities and programming. This event has been held virtually, with an increasingly global and growing audience. The Applications Program hosted its fourth virtual workshop September 6–7, 2023. A total of 1000 workshop registrants from more than 97 countries included satellite operators, satellite data users, applications developers, applications users, decision makers, and members of PACE user communities ranging from novice to experienced. As with previous workshops, the event brought together an international community of academics; government partners at the federal, state, and local levels; and participants from private organizations, including nonprofit and nongovernmental organizations (NGOs). This workshop follows a series of successful workshops that have been facilitated over the last four years, two of which were summarized in previous articles in *The Earth Observer*.[1]

Framing the 2023 Workshop

As shown in **Figure 1** on page 26, PACE Applications continue to follow a progression of thematic focus areas and priorities in each workshop, with an overall goal of partnership development, end-user and stakeholder engagement, information sharing and awareness building, and the growth of existing and new applications. In 2020, the event focused on community research, including better understanding the diversity of the community and their needs, priorities, challenges, and barriers. Communities included *Early Adopters* (EAs),[2] Science and Applications Team (SAT) members, and other users and stakeholders. In 2021, the priority included coproduction and collaboration within PACE thematic areas (e.g., air quality, water quality, climate, terrestrial disasters). Speakers and panelists included scientists, users, data developers, and others who could assess and develop a shared understanding of community needs. In 2022, the workshop focused on identifying action steps to address the challenges raised during previous years. The agenda included discussions on how to move forward toward launch and prepare applications for future PACE data. The participants also discussed the coproduction of applications, decision support tools (DSTs), and effective engagement strategies to make them as effective as possible.

Though still tentative, the 2024 workshop will feature applications of PACE post-launch, including case studies, trainings and tutorials on accessing and applying PACE data, measuring impact, and how users can ultimately achieve sustained use. As the first workshop post-launch, it is expected that users will be featured heavily in the agenda in sharing their experiences,

[1] To learn more about the first PACE Applications Workshop, see **Leveraging Science to Advance Society: The 2020 PACE Applications Workshop** in the November–December 2020 issue of *The Earth Observer* [**Volume 32**, **Issue 6**, pp. 18–26]. To learn more about the second PACE Applications Workshop, see **Partnerships, Co-Production, and Transdisciplinary Science: The 2021 PACE Applications Workshop** in the November–December 2021 issue of *The Earth Observer* [**Volume 33**, **Issue 6**, pp. 14–23].
[2] Early adopters engage in pre-launch and post-launch activities to demonstrate the utility of a particular mission's data (in this case, PACE) for applications that benefit society.

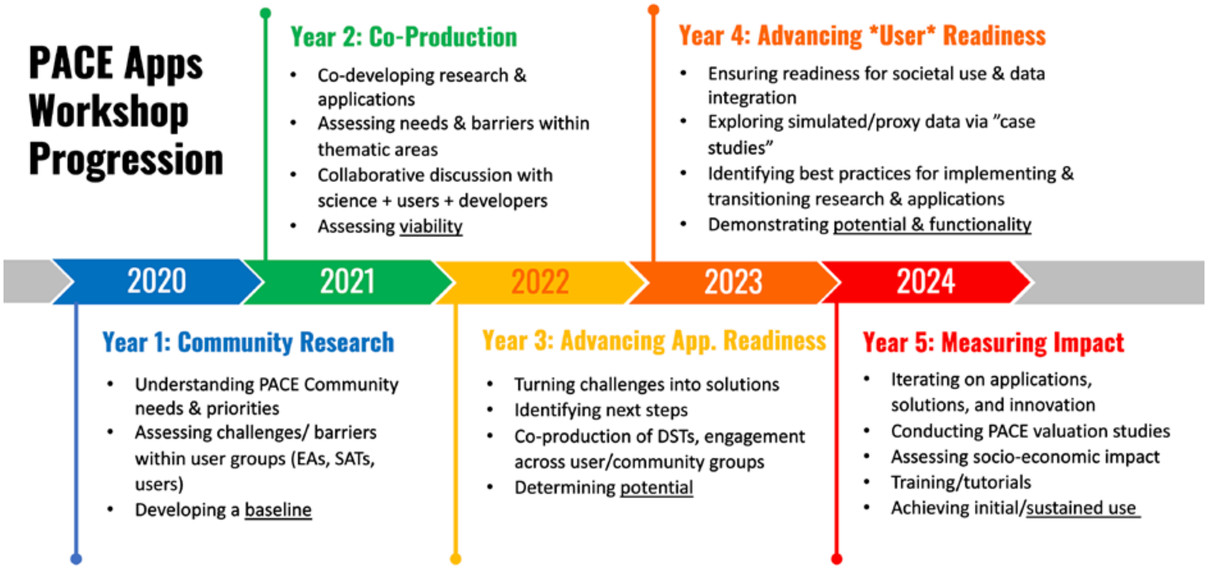

Figure 1. PACE Applications Workshop Progression from 2020 to 2025. **Image credit:** NASA PACE Applications Program

learning from each other, and promoting further use and application of PACE data.

This article summarizes the 2023 workshop. It includes a summary of the materials presented and discussions during the 2023 workshop (year 4 from Figure 1), while also discussing the broader topic of end-user readiness in the context of a new mission. Rather than organize the information by session and report chronologically, the content is organized around the four workshop objectives (see next section). This approach illustrates how an intentional, creative, and diverse program of workshop activities could achieve the workshop's overarching goals. The full workshop agenda, speaker biographies, and recordings of the keynote presentations, panel sessions, breakout sessions, and engagement activities are available at the **workshop website**.

Workshop Motivation, Theme, and Objectives

The upcoming PACE mission represents a major advancement in Earth observation capabilities—particularly the hyperspectral and multi-angle polarimetric measurement capabilities of its instruments. Clearly, there is a great deal that the science and applications community can potentially gain from and do with these new observations. However, while there has been an intentional effort the past few years to make users more aware of the capabilities of PACE, many still don't feel prepared to utilize the PACE data once they become available, which will be after PACE launches and passes initial checkouts of the spacecraft and instrument performance (likely by mid-2024).

A preworkshop questionnaire—results shown in **Figure 2**—conducted among registrants helped to quantify these concerns. It was an assessment of the state of

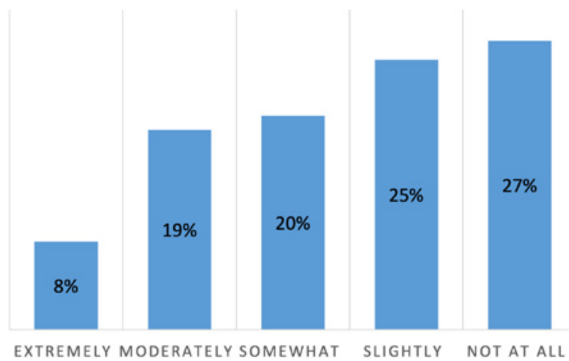

Figure 2. Responses to a pre-workshop questionnaire assessing respondents' readiness to use PACE data (total respondents: 993). **Image Credit:** PACE Applications Program.

user readiness to use PACE data by launch or shortly thereafter. The results of the questionnaire indicate that a substantial portion of the PACE community (including stakeholders and potential science and application users) feel *underprepared* to use PACE data by the time it is available—as indicated by the 73% who responded to the survey that they were *somewhat*, *slightly*, or *not at all* prepared to utilize PACE data. By contrast, only 8% responded that they were *extremely* prepared to use PACE data from "day one" of its availability.

This survey helps to confirm that the perceived "gap" in user readiness is quite real. This gap motivated the theme of the 2023 PACE Applications workshop—*user readiness*— which focused on preparing the PACE community for the eventual uptake of PACE data. PACE Applications work toward several user-readiness goals, as listed in the bullets below.

- *Communicate Progress*: Communicate the progress and updates from the PACE mission, including data stream availability, training activities, and essential information that PACE users need to be ready. PACE-user preparedness requires transparency and accessibility to this information.

- *Raise Awareness*: Increase public awareness of the unprecedented capabilities and advancements of the upcoming PACE mission, including the benefit of PACE data to society through informed decision making.

- *Emphasize Value*: Make users and decision makers aware of the intrinsic value, the diverse types, and the sources of PACE data. Understanding the potential applications and the real-world relevance of PACE data is a key step towards advancing readiness.

To achieve these goals, PACE Applications developed a comprehensive user-readiness checklist for the mission, ensuring that:

- users are aware of the changes and updates being made to the PACE mission and understand their implications;

- training resources are readily available or actively being developed to equip users with the necessary skills and knowledge;

- participation and feedback channels for various user-readiness activities are well-documented, fostering a collaborative community;

- questions and concerns from users are addressed promptly, leaving no room for ambiguity; and

- user-readiness information is easily attainable, promoting accessibility and inclusivity.

The 2023 PACE Applications workshop focused on user readiness to provide the community with the knowledge, tools, and resources needed to employ the full potential of PACE Earth science data for impact. By focusing on user readiness, PACE Applications aimed to bridge the gap, inspire data confidence, and support successful application of PACE data after launch. Given the importance of user readiness in preparing for launch and the user-readiness checklist, the 2023 PACE Applications workshop objectives aimed to:

1. provide an overview of the PACE mission, the observatory, and the societal applications, ensuring attendees have a clear understanding of PACE's significance;

2. share information about tools, ideas, and best practices in preparation for PACE data use;

3. demonstrate simulated datasets and PACE data integration examples, allowing users to gain practical insights into data handling and analysis; and

4. consider important perspectives for the implementation and transition of PACE applications, emphasizing their potential for broad societal impact.

Workshop Overview and Structure

The organization of the 2023 PACE Applications Workshop enabled opportunities to connect, contribute, and collaborate. Prior to the event, workshop organizers polled registrants to share their backgrounds, expertise, interests, and demographics to facilitate a relevant workshop with engaging conversations. The two-day workshop agenda included daily icebreaker activities, which were an effective way to welcome participants and encourage participation and engagement early and throughout the event.

The morning session included an introduction to NASA Earth science, the PACE Applications Program, and Design Thinking for data science. **Natasha Sadoff** [NASA's Goddard Space Flight Center (GSFC)/Science Systems and Applications, Inc. (SSAI)—*PACE Applications Deputy Coordinator*] and **Erin Urquhart** [GSFC/SSAI—*PACE Applications Coordinator*] served as co-hosts for the event. They opened each day of the workshop with information on workshop logistics and engagement activities, followed by a brief overview of NASA's PACE Applications and the Early Adopters (EA) program, both of which serve as mechanisms to build prelaunch partnerships between PACE data producers and data users.

Dalia Kirschbaum [GSFC—*Director of Earth Sciences*] gave the first plenary presentation. She introduced NASA Earth science at Goddard and across NASA, including how PACE fits into the fleet of Earth science missions. Kirschbaum also outlined the role of user feedback and engagement in the new **Earth Science in Action** strategy recently adopted by NASA, including public understanding and awareness and user preparation as the key to mission success. She outlined user involvement in mission planning, user preparation through EA programs, and user support applying mission data within decision-making contexts.

Erin Urquhart discussed user readiness from the PACE Applications perspective. She described the user-readiness goals and checklist mentioned above. She also outlined ways in which the PACE Applications program uses *design thinking*[3] and coproduction methodologies to understand preparedness and needs as well as codesign possible solutions for increasing readiness. For example, PACE Applications worked with the

[3] Design thinking is a solution-based, problem-solving approach that assesses people's needs and the impacts decisions made will have on them.

community to identify illustrative user profiles (personas) and their respective data accessibility and functionality requirements. The team then worked in small breakout groups to identify possible solutions.

Bo Peng [IDEO—*Portfolio Manager*] provided broader context on human-centered design and design thinking to identify ways in which these approaches can be incorporated into data science projects. She emphasized that data by itself does not inspire innovation, action, or change. Instead, teams should start with people (i.e., users) and use insights and human stories to drive impact—which references the same design thinking method mentioned by Erin Urquhart in the previous presentation.

Following the workshop introduction (Session 1) described above, the four subsequent technical sessions were:

- Session 2: PACE Mission & Science: Ready for Launch!
- Session 3: User Readiness: Are YOU Ready for Launch?
- Session 4: The "Hows and Whys" of PACE Data Integration.
- Session 5: Onward and Upward: Transition and Implementation.

In addition to these sessions, a virtual poster session held on day one of the workshop allowed members of the community to share their work, including how they are preparing for the PACE launch. Though the live session took place on day one, the posters were visible to participants throughout the event.

The remainder of this report is organized according to workshop objectives and does not necessarily reflect the linear agenda, which is found on the **PACE Workshop website**.

Objective 1: Provide an overview of the PACE mission, observatory, and science

The first objective of the workshop was to provide an overview of the PACE mission, observatory, and broad societally relevant applications. As the largest PACE event of the year, this workshop introduces community members to the mission as well as providing science updates, even if unrelated to specific applications. According to the pre-workshop questionnaire, 75% of this workshop's audience self-identified as new to PACE—highlighting the importance of this objective.

Jeremy Werdell [GSFC—*PACE Project Scientist*] and **Mark Voyton** [GSFC—*PACE Project Manager*] introduced the PACE mission, observatory, data products, and hardware updates. Werdell provided an overview of the three instruments included on the PACE observatory: the **Ocean Color Instrument** (OCI) (a hyperspectral radiometer) and two contributed multi-angle polarimeters {the **Hyper Angular Research Polarimeter** (HARP2) and the **Spectro-polarimeter for Planetary Exploration** (SPEXone)}. He discussed the conception and history of the PACE mission, its status, and the array of data products planned to address data needs that span the ocean, land, and atmosphere. He also introduced simulated data from all instruments, including OCI data from the **Python Top-of-Atmosphere Simulation Tool** (pyTOAST). All simulated data products are available on the **Simulated and Proxy Data website**. Voyton provided an overview of the hardware, integration and testing (I&T), and schedule in the remaining months prior to launch.

Alicia Scott [GSFC/SAIC—*Deputy Manager of the Ocean Biology Distributed Active Archive Center* (OB.DAAC)] introduced NASA's distributed active archive centers (DAAC) to access NASA's freely available data and the **OB.DAAC** to meet users' needs in terms of data and services related to ocean color data and beyond. As the future home of all PACE data, OB.DAAC provides PACE users with a variety of resources, including data visualization and ordering tools, as well as user services, such as trainings and other resources to support user uptake of OB.DAAC data.

Panel Discussion: How PACE Discipline Scientists are Preparing for Launch

This panel consisted of presentations from and conversations between the six PACE Deputy Discipline Scientists (DS) and the workshop participants. The panelists discussed the various science elements that converge in the PACE mission and how preparations for launch are progressing. Panelists included:

- **Brian Cairns** [NASA's Goddard Institute for Space Studies (GISS)/Columbia Univ—*DS for Atmosphere and Air Quality*]
- **Kirk Knobelspiesse** [GSFC—*DS for Polarimetry*]
- **Ivona Cetinic** [GSFC/MSU—*DS for Ocean Biogeochemistry and Bio-optics*]
- **Amir Ibrahim** [GSFC—*DS for Atmospheric Correction*]
- **Cecile Rousseaux** [GSFC—*DS for Level-4 Products*]
- **Fred Huemmrich** [University of Maryland, Baltimore County—*DS for Terrestrial Science*]

The panel started with a summary of key information from each Project Science element, including the latest updates, state-of-standard and advanced products, and where to find more information. The discussion touched upon validation, atmospheric correction, opportunities for community feedback, and noteworthy synergies from other remote sensing datasets or future missions, such as National Oceanic and Atmospheric Administration's (NOAA) **Geostationary Extended Observations** (GeoXO) mission, NASA's **Geosynchronous Littoral Imaging and Monitoring Radiometer** (GLIMR), **Atmosphere Observing System** (AOS), and **Surface Biology and Geology** (SBG) missions, and lidar systems [e.g., **High Spectral Resolution Lidar** (HSRL)].

Objective 2: Share information about tools, ideas, and best practices in preparation for PACE data

Users require tools, ideas, and best practices to be ready for the PACE launch and ultimately, for the flow of PACE data. Session 3, *User Readiness: Are YOU Ready for Launch?* addressed this objective through various presentations and discussion. **Sabrina Delgado Arias** [GSFC/SSAI—*Ice, Clouds, and Land Elevation Satellite–2 (ICESat-2) Applications Lead*] gave a plenary presentation sharing best practices from the **ICESat-2** mission, which launched in September 2018. This example provides a unique look into pre- and post-launch user-readiness activities from which PACE could learn. Delgado Arias noted that user preparedness requires relationships; sustaining and maintaining relationships requires a continuous effort and continuity of personnel. Applications Programs can and should be liaisons between data users—who are "insiders" and "ambassadors" of the data, instrument, and mission—and the rest of the Project Science, the Science Data Segment, and the DAAC.

Melanie Follette Cook [GFSC—*NASA ARSET Project Scientist*] provided an overview of NASA tools and resources, including those offered through NASA's **Capacity Building Program**, which includes the SERVIR, DEVELOP,[4] and Applied Remote Sensing Training (ARSET) programs under its auspices. DEVELOP bridges the gap between Earth science information and society through 10-week terms with early career scientists and students. SERVIR, a joint development initiative between NASA and the U.S. Agency for International Development (USAID), provides local decision-makers with the tools, training, and services they need to act on climate-sensitive issues like disasters, agricultural security, water management, and land use. With a focus on sustainability, those solutions are available and promoted throughout the region and globally. ARSET, a popular training program, offers online and in-person trainings that range from introductory to advanced. Trainings relevant to PACE include topical trainings on smoke and dust transport, water and air quality monitoring, or coastal ocean ecosystem dynamics and management, as well as introductory trainings on remote sensing basics and data formats and access. Future training modules may focus on applications using hyperspectral and polarimetry data from PACE and other relevant missions. Outside of the Capacity Building Program, other resources include the **Early Adopter Handbook**, which provides information on NASA's EA Strategy with recommendations for effective implementation based on lessons learned over the past decade, and the **Earth Science Applications Guidebook**, which translates decades of experience in applying information into shareable knowledge and practical guidance that may support users as they explore PACE application areas. Finally, the **Earth Data Pathfinders** offers topic-specific data resources.

Kim Hyde [NOAA Fisheries—*Biological Oceanographer*] shared important considerations for data interoperability and preparing tools for PACE data based on her experience with ocean color data within **NOAA Fisheries**. Though complicated to enact, NOAA Fisheries aims to take an ecosystem-based approach to management, providing services for their stakeholders working in fisheries management, ecosystem monitoring, and public health. The agency uses a variety of ocean color products for water mass classification, improved coastal algorithms, phytoplankton composition and harmful algal bloom detection, and improved operational forecasts, models, and management.

Ashutosh Limaye [NASA MSFC—*SERVIR Chief Scientist*] provided an overview of some best practices from the SERVIR "service approach" that users could consider in preparation for PACE. The **SERVIR Service Planning Toolkit** utilizes a similar method as design thinking in its focus on coproduction and codesign of problems and solutions. Limaye encouraged attendees to conduct consultations and needs assessments, stakeholder mapping, service design, and monitoring, evaluation, and learning activities to ensure that their research or applications are ready for new data streams, such as PACE, in their efforts to meet user and societal needs.

Objective 3: Demonstrate simulated datasets and PACE data integration examples

Session 4, The "*Hows and Whys" of PACE Data Integration*, addressed the third objective. The 75 engagement activity survey responses received—see **Figure 3** on page 30—show that the PACE community

[4] Neither SERVIR nor DEVELOP are acronyms. SERVIR is a Spanish word meaning "to serve," which describes what the program does for people living in places where it operates. DEVELOP likewise represents the program's objective of developing and enhancing the careers of aspiring young scientists.

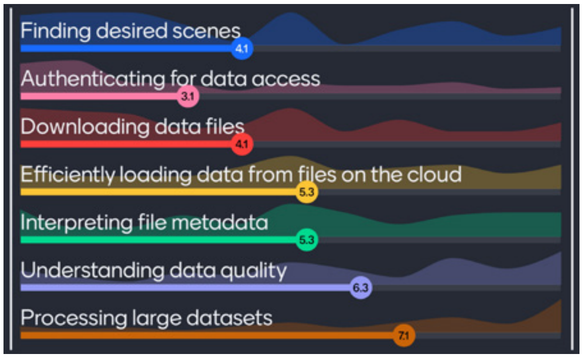

Figure 3. Engagement activity statements and responses collected to assess level of PACE user concern with aspects of data discovery, access, and processing on September 7, 2023 (total respondents: 75). Numbers are scale values of 1 (not concerned) to 10 (extremely concerned). **Image Credit:** PACE Applications Program using Mentimeter.com.

continue to have concerns about several areas of PACE data readiness. Some of these concerns were addressed during the workshop—however many will be addressed in the coming months by NASA through training, tutorials, and other resources. Session 3 also provided participants with case studies, lessons learned, and broader information about integrating PACE data within existing applications.

Emerson Sirk [GSFC/SSAI—*Scientific Programmer*] and **Meng Gao** [GSFC/SSAI—*Polarimetry Software Lead*] each gave presentations on simulated data from OCI and the two multi-angle polarimeters, respectively. All PACE simulated data[5] were developed for internal team use in testing algorithms, code, and models. These data also help future users of PACE data gain familiarity with the data format, geometry, grids, and resolution that PACE data will have—although Sirk did emphasize that the simulated data are not *science quality* for conducting research. As noted previously, simulated data are available on OB.DAAC. Also, PyTOAST provides simulated hyperspectral data from OCI at Level1B (L1B), L2, and L3, including all standard geophysical products. The multi-angle polarimetry data is high quality for testing aerosol and ocean color retrieval algorithms, with reflectance and polarization available at L1 and aerosol and ocean color retrievals and uncertainties available at L2. More information on coverage and limitations for each individual instrument can be found through OB.DAAC.

Nima Pahlevan [GSFC/SSAI—*Remote Sensing Scientist*], **Chuanmin Hu** [University of Florida—*Professor*], and **Marcela Loría Salazar** [University of Oklahoma—*Assistant Professor*] discussed their experience with integrating PACE data into their applications, including coastal and freshwater ecosystems, sargassum and oil spills, and aerosols and weather, respectively. Each team integrated PACE data in different ways. Pahlevan and Hu used observations from the **Hyperspectral Imager for the Coastal Ocean** (HICO)—which flew on the International Space Station from 2009–2014—to demonstrate hyperspectral capabilities in proof-of-concept work. Pahlevan's team also worked with users on readiness by providing information on validity, quality, viability, and caveats. Similarly, Loría Salazar recognized the challenges of using Earth observation for air quality models given large spatial gaps and aggregating data despite biases. PACE plans to improve the spatial resolution of **Moderate Resolution Imaging Spectroradiometer** (MODIS) aerosol products for aerosol optical depth and aerosol layer height retrievals. However, to prepare for PACE, Loria Salazar continues to develop and test her models with proxy data from other satellites, models, and aircraft/ground-based sources.

Objective 4: Consider important perspectives for implementation and transition of PACE applications for broad impact

The fourth objective of the 2023 PACE Applications workshop, and core focus of session 5: *Onward and Upward: Transition and Implementation*, was to examine important perspectives for the implementation and transition of PACE applications, emphasizing their potential for broad societal impact. Specifically, two main themes emerged—the importance of involving diverse communities and stakeholders to enhance applications (as echoed during the workshop engagement activity—see **Figure 4**) and explore practices that contribute to the successful transition and use of Earth observing data via Earth science applications. Session programming hoped to encourage forward-thinking regarding PACE research and applications and to prompt the PACE community to consider transition and implementation strategies early and often.

Amber McCullum [NASA Ames Research Center (ARC)/Bay Area Environmental Research Institute—*Applied Research Scientist*] provided an overview of the

Figure 4. Characteristics of a diverse and inclusive community from the September 7, 2023, engagement activity responses (total respondents: 49). **Image Credit:** PACE Applications Program, Mentimeter.com

[5] Note that—for PACE—simulated data are different from proxy data. Simulated data are those actually simulated from other data sources, while proxy data are those coming from existing data sources—e.g., MODIS chlorophyll-a is a proxy dataset for future PACE chlorophyll data.

NASA Western Water Applications Office (WWAO) and considered insights, challenges, and lessons learned in the successful transition of applications to operation. She emphasized the importance of involving partners before and during application scoping via codevelopment, transitioning planning and discussion from the start of a project, and sustained capacity building to ensure data/products/tools become an integral part of the decision-making processes.

Panel Discussion: Onward & Upward

Kelly Luis [NASA Jet Propulsion Laboratory (JPL)—*Postdoctoral Researcher*] moderated this panel session, which focused on shedding light on transitioning Earth science applications and research to operation (R2O). The four panelists offered varying perspectives spanning the commercial, academic, and government arena. Each panelist shared their experience with, and challenges encountered when using Earth science applications by addressing the following questions: *How do we systematically approach the topic of transitioning Earth science research and applications to action? What advice can you lend to those who are transitioning their own R2O?*

Yaítza Luna-Cruz [NASA Headquarters] reminded attendees of the importance of early engagement. "Earth science to action," she emphasized, "we need to engage with everyone, early in the early phases of the mission." Recognizing that Earth science does not operate in a vacuum, Luna-Cruz advocated for collaboration across various sectors, stressing that "there is a place for interagency collaboration, for private sector collaboration, and for academic collaboration." She highlighted the necessity of inclusivity and partnership in bringing Earth science research to action.

Blake Schaeffer [U.S. Environmental Protection Agency (EPA)] offered a perspective that underscores the significance of understanding the technological landscape. "Keep the larger context in mind," Schaeffer advised, "and where we [and users] are on the technology adaptation lifecycle." Additionally, he underscored the importance of continuous capacity building, noting "training needs to continually happen." Furthermore, he suggested taking advantage of communication networks that play a vital role in success stories and inspire others to embrace new tools, services, and applications.

Raha Hakimdavar [Zyon Space] represented the private sector and offered perspectives on the agility and scale that private companies can provide. She suggested that "in theory, a private company can move more quickly and scale more quickly than within a larger bureaucracy (e.g., the Federal government)." Hakimdavar also proposed a public–private–academic partnership model to facilitate the codevelopment of research and its transformation into commercial products and applications where appropriate.

Kari St. Laurent [NOAA National Environmental Satellite, Data, and Information Service (NESDIS)] shared practical advice on operationalization and engagement with users. She advised that, when transitioning research to operation, one must be "considerate of users' time and make sure your interactions are meaningful." St. Laurent noted practicality in understanding the time investment required for operationalization, stating that "operationalization of a product is a major time investment; being realistic of the time it takes to operationalize a product is crucial." She reiterated that time is of the essence when striving for operational success and mentioned that "[users] need to be mindful of operational milestones."

After the panel, the workshop organizers concluded this discussion with an important perspective and call to action for the entire community—the PACE team, including Applications and other parts of Project Science, as well as OB.DAAC, ARSET, and other stakeholders within and outside of NASA, have a role in preparing users for PACE data; however, users must do *their* part in advancing their own PACE data readiness. This crosses all the various elements of user readiness that were introduced during the workshop: understanding data, accessing data, handling data, analyzing data, and applying knowledge.

Workshop Recommendations and Feedback

As indicated through a variety of metrics—including the reach, the number of participants, and the positive feedback on the agenda, speakers, and panels—the fourth annual PACE Applications Workshop was a success. As a virtual forum, the workshop achieved an incredible level of global interest and multidisciplinary turnout, with a high level of engagement and interaction among the hosts, presenters, and participants. Despite being fully virtual, participants appreciated the opportunities for engagement and networking, with one person observing it was "hands down the most engaging and informative remote workshop I've been able to participate in." Participants also appreciated the *Swapcard* event platform, including its functionality for chats, meetings, and other types of networking, as well as the use of Mentimeter.com, as an engagement tool. With participants from over 97 countries, this was the most far-reaching workshop yet geographically.

As noted earlier, the PACE community, as represented in the registrants, continues to diversify across sectors and thematic areas. The agenda continues to provide clear objectives and logical flow from year to year. One participant noted that "just 10 years ago these big conversations of coproduction and engagement, inclusivity, equity, and community never would have been conversations we had at the mission level." The workshop enabled a transdisciplinary dialogue focused on the PACE mission and how users can prepare for and ultimately utilize PACE data.

Conclusion

The workshop supported the PACE mission and broader NASA Earth Action initiatives, continuing momentum toward PACE launch and beyond. The 2024 annual workshop—anticipated to occur in-person and be the first postlaunch gathering of this community—will focus on impact, including iterating on applications, solutions, and innovation; conducting PACE validation studies; assessing socio-economic impact; producing tutorials and trainings; and achieving initial, sustained use. The NASA PACE Applications Program team will continue to engage and interact with applied-research, data-user, and stakeholder communities to solicit feedback to inform future mission and application activities. As always, the PACE Applications Program website will continue to post news of future meetings and events.

Update from the Executive Editor on the Continued Evolution of *The Earth Observer*

The Earth Observer ended its long run as a NASA print publication at the end of 2022. At that time, the newsletter's production team committed to a transition period during which we would continue to publish bimonthly issues of the newsletter—throughout 2023—as we planned for "the next step" in the process. Beginning in 2024, we will implement that next step as the newsletter adopts a new fully online publication format, allowing each article to be published individually upon completion. This move will enable *The Earth Observer* more flexibility to deliver timely content to our readers.

Committing entirely to a virtual medium after **35 Volumes of printed/PDF issues** is a big step for our publication. While this move will shift *The Earth Observer*'s *format* more in line with that of other online publications, our intent is for its *content* to continue to make this newsletter distinctive. Readers can expect the same quality reporting on NASA Earth Science activities that they have come to depend on from *The Earth Observer* for almost 35 years to continue as we move to publishing online. On behalf of the production team, I want to thank our readers for their patience and adaptability during this time of transition and extend my heartfelt gratitude to all of you for sticking with us on this journey.

—**Alan Ward** [Executive Editor, *The Earth Observer*]

In Memoriam: Mary Cleave [1947–2023]

Acclaimed NASA astronaut, engineer, and administrative leader Mary Cleave died on November 27, 2023, at age 76. Her very full and impactful 27-year NASA career started in 1980 when she became an astronaut based at Johnson Space Center (JSC), following which she was a Project Manager at Goddard Space Flight Center (GSFC) and then an administrator at NASA Headquarters. In each of her roles, Mary was a dedicated, no-nonsense, enthusiastic contributor, and she is now being mourned by many who knew and worked with her.

Mary Cleave [1947–2023]. **Photo credit:** NASA

Mary was born on February 5, 1947, in Southampton, NY, and grew up in Great Neck, NY, graduating from Great Neck North High School in 1965. She received a bachelor's degree in biological sciences in 1969 from Colorado State University, a master's degree in microbial ecology in 1975 from Utah State University, and a Ph.D. in civil and environmental engineering in 1979 from Utah State University. While in graduate school and continuing until June 1980, Mary worked at the Utah Water Research Laboratory and the Ecology Center at Utah State University, tackling such topics as the effects of increased salinity on freshwater phytoplankton productivity.

Mary was selected as a NASA astronaut in May 1980 and five years later became the tenth woman to fly in space, doing so on the first of her two Space Shuttle missions, STS-61B on Space Shuttle *Atlantis* in 1985. She was the STS-61B's flight engineer, operated the Shuttle's robotic arm, and conducted a set of experiments for the 3M company. In 1989, Mary flew on her second Space Shuttle mission, STS-30, also on *Atlantis* (see **Photo** on page 34), becoming the first woman to fly on the Shuttle after the devastating 1986 *Challenger* explosion. During STS-30, Mary deployed the *Magellan* spacecraft on its journey to Venus, where it collected valuable information about the Venusian surface, atmosphere, and magnetic field, mapping more than 95% of the planet's surface. Altogether, Mary was in space for 10 days and 22 hours, orbiting the Earth 172 times and traveling 3.94 million miles. She was also capsule communicator (CAPCOM) for five additional Shuttle flights.

In 1991, Mary moved to Maryland and began work at GSFC, eventually becoming Project Manager for the Sea-viewing Wide-Field-of-View Sensor (SeaWiFS), which was designed to make global measurements of the Earth's oceans. The SeaWiFS mission had been in danger of being canceled when Mary took over and assertively reset its course, leading it through to its successful 1997 launch on the OrbView-2 satellite. For the next 13 years, SeaWiFS collected an extremely valuable dataset that has been used in hundreds of scientific publications, as well as being used operationally by the NOAA Coast Watch Program, the U.S. Marine Fisheries Service, and the U.S. Geological Survey, especially to monitor coastal water quality, including red tides, clarity, and sedimentation in coastal and estuarine waters.

In 1998, Mary moved to NASA Headquarters, where she became the first woman to lead NASA's Science Mission Directorate (SMD). As Associate Administrator for SMD, Mary had responsibilities that extended from Earth environmental measurements to spacecraft probing the outer reaches of the Solar System and the universe at large, overseeing a large variety of research programs and satellite missions. Among her many contributions, she provided visionary leadership by encouraging a long-term carbon research program to address Earth's growing problems with human impacts on the environment and climate.

When Mary retired from NASA in February 2007, her initial plan was to unwind for several months and then seek a new full-time job. However, she quickly found that she so enjoyed the freedom of picking and choosing what to do and when to do it that she happily abandoned the thought of another full-time job. Instead, she

Photo. Mary at work on the Space Shuttle Atlantis, May 1989. **Photo credit:** NASA

filled her time with enjoyable, meaningful volunteer activities, speaking frequently to students and adults about her astronaut experiences, encouraging girls in particular to pursue interests in science and engineering, participating annually at the National Air and Space Museum's Women in Aviation Day, volunteering with the Maryland Science, Technology, Engineering, and Mathematics (STEM) Festival, the Maryland Women's Heritage Center (MWHC), the League of Women Voters, and a dog-rescue group, as well as serving on the Annapolis Commission on Aging and on a variety of corporate boards and advisory committees. She maintained a full schedule of activities while also enjoying time visiting with family and friends and taking in the beautiful view of Chesapeake Bay from her Annapolis condominium.

Mary was inducted into the Long Island Air and Space Hall of Fame in 2010 and the Maryland Women's Hall of Fame in 2022. Her NASA awards include the NASA Space Flight Medal, the NASA Exceptional Service Medal, the NASA Exceptional Achievement Medal, and the NASA Engineer of the Year award.

Mary is survived by her sister Gertrude "Trudy" Carter and her sister Barbara "Bobbie" Cleave Bosworth. She will be missed by many in the NASA family and elsewhere as an enthusiastic, inspiring, kind, and thoughtful individual who lived a full and exciting life and was dedicated to helping others to have the opportunity to do the same.

Acknowledgments: *The Earth Observer* staff wishes to thank **Claire Parkinson** [GSFC] for writing this *In Memoriam*, and Claire thanks **Chuck McClain** [GSFC, retired] and **Dot Zukor** [GSFC] for carefully reviewing the text pre-publication.

NASA, Partners Explore Sustainable Fuel's Effects on Aircraft Contrails

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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 edited for the context of *The Earth Observer*.

Contrails, the lines of clouds from high-flying aircraft that crisscross the skies, are familiar sights, but they may have an unseen effect on the planet—trapping heat in the atmosphere. Working with Boeing, and other partners, NASA researchers are collecting data to see how new, greener aviation fuels can help reduce the problem.

During October, NASA and Boeing partnered to conduct a contrail research campaign in Washington state through the company's ecoDemonstrator program. The campaign focused on generating and analyzing data about sustainable aviation fuel's capacity to benefit the environment.

Boeing's second ecoDemonstrator Explorer aircraft, a 737-10, conducted test flights switching between tanks filled either with 100% sustainable aviation fuel or a low-sulfur version of conventional jet fuel. NASA's DC-8 aircraft, the world's largest flying science laboratory, followed, measuring emissions and contrail ice formation from each type of fuel—see **Photo 1**.

Photo 1. NASA Armstrong's DC-8 aircraft flies over the northwestern U.S. to monitor emissions from Boeing's ecoDemonstrator Explorer aircraft. As the largest flying science laboratory in the world, the DC-8 is equipped to collect crucial data about the sustainable aviation fuel and its effects on condensation trail formation. **Photo credit**: Jim Ross/NASA

The data collected by the DC-8's special instrumentation—see **Photo 2**—will help determine whether sustainable aviation fuels help reduce the formation of contrails.

Photo 2. NASA researchers on board the DC-8, tracking data coming in via its many sensors. **Photo credit**: Steve Freeman/NASA

"Contrails are believed to be a major source of pollution," said **Rich Moore** [NASA's Langley Research Center (LaRC)], a research physical scientist in the Aerosol Research Group Experiment and principal investigator for the campaign. "With this flight campaign, we're looking not so much at correcting contrails—but at preventing them."

In addition to the DC-8, which is based at NASA's Armstrong Flight Research Center, the agency contributed other critical capabilities, including a mobile laboratory for ground testing. Other collaborators for the flight campaign included GE Aerospace, the Deutsches Zentrum für Luft- und Raumfahrt (DLR) [German Aerospace Center], the Federal Aviation Administration, and United Airlines. Within a year, the researchers will publish their results.

"One of the most amazing things about this collaboration is that this data will be released publicly to the world," Moore said.

Contrail clouds can have both localized cooling or warming effects depending on conditions and timing, but researchers' computer estimates say their warming effect is greater on a global scale. Over the past several years, NASA has worked with partners to match those models with observations, working to understand how and when contrails form, and their impact on the environment.

Photo 3. The DC-8 in its "home away from home" at the Aviation Technical Services facility in Everett, Washington. **Photo credit**: NASA/Jim Ross

Jet engine exhaust includes water vapor and soot particles. Contrails form when aircraft operate in the cold temperatures at high altitudes. The water vapor in their exhaust cools and condenses, and when it interacts with either the soot or other particles in the air, it forms ice crystals. Those contrails can linger in the upper atmosphere for hours, producing localized temperature impacts, which over time can affect climate change.

Alternative fuels, including sustainable aviation fuels, can release fewer soot particles. Research models find that this should result in fewer crystals—and the ones that do form will be larger—falling and melting in the warmer air below—reducing contrails' environmental impact.

In addition to this newest ecoDemonstrator partnership, NASA and DLR have previously conducted **joint flight research campaigns** known as ND-MAX.[1] These campaigns involved the DC-8 testing contrails left by an A320 airliner operated by DLR that used biofuels. In 2013 and 2014, NASA led a **series of research flight programs** utilizing smaller, business-class jets called Alternative Fuel Effects on Contrails and Cruise Emissions.

Over the past decade, NASA-funded research has shown that sustainable aviation fuels have significant benefits for reducing engine particle emissions that can influence local air quality near airports and contribute to the formation of contrails. Efforts to develop and evaluate sustainable aviation fuels focus on delivering the performance of conventional jet fuel without releasing new carbon dioxide into the environment. These fuels can be derived from sustainable sources such as feedstocks and waste resources. NASA's sustainable aviation fuel research is part of the agency's work to advance the U.S. goal of net-zero aviation greenhouse gas emissions by 2050.

Flight testing remains the gold standard for understanding aerospace innovations and their environmental impacts, making partnerships like ecoDemonstrator and research aircrafts like NASA's DC-8—see **Photo 3**—important sources for data that can help make aviation more sustainable, protecting the environment and improving life on Earth. ■

[1] NASA refers to these campaigns as NASA–DLR Maximum Research Opportunity (or ND-MAX); DLR refers to the study as **Emission and Climate Impact of Alternative Fuel** (ECLIF).

NASA, Pacific Disaster Center Increase Landslide Hazard Awareness

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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 edited for the context of *The Earth Observer*.

After years of development and testing, NASA's **Landslide Hazard Assessment for Situational Awareness model** (LHASA) has been integrated into the Pacific Disaster Center's (PDC) multi-hazard monitoring, alerting, and decision-support platform, **DisasterAWARE**. LHASA allows researchers to map rainfall-triggered landslide hazards, giving DisasterAWARE users around the world a robust tool for identifying, tracking, and responding to these threats. The aim is to equip communities with timely and critical risk awareness that bolsters disaster resilience and safeguards lives and livelihoods.

Landslides **cause thousands of deaths** and billions of dollars in damage every year. Developing countries often bear **disproportionate losses** due to lack of access to hazard early warning systems and other resources for effective risk reduction and recovery. Reports from the **United Nations Office for Disaster Risk Reduction** emphasize that early warning systems and early action are among the most effective ways to decrease disaster-related deaths and losses—see **Photo 1**.

"Some local authorities develop their own systems to monitor landslide risk, but there isn't a global model that works in the same way. That's what defines LHASA: it works all the time and it covers most regions of the world," says **Robert Emberson** [NASA's Goddard Space Flight Center (GSFC)—***NASA Disasters*** *Associate Program Manager* and *Member of the* ***NASA Landslides Team***]. "Thanks to our collaboration with the Pacific Disaster Center, this powerful landslide technology is now even more accessible for the communities that need it most."

LHASA uses a machine learning model that combines data on ground slope, soil moisture, snow, geological conditions, distance to faults, and the latest near **real-time precipitation data** from NASA's IMERG product (part of the Global Precipitation Measurement mission). The model has been trained on a **database of historical landslides**—see **Figure 1** on page 38—and

Photo 1. A humanitarian worker from the United States Agency for International Development (USAID) observes the impacts of a landslide. USAID deployed an elite Disaster Assistance Response Team on November 17, 2020, to lead the U.S. response to Hurricanes Eta and Iota. **Photo credit:** USAID's Bureau for Humanitarian Assistance

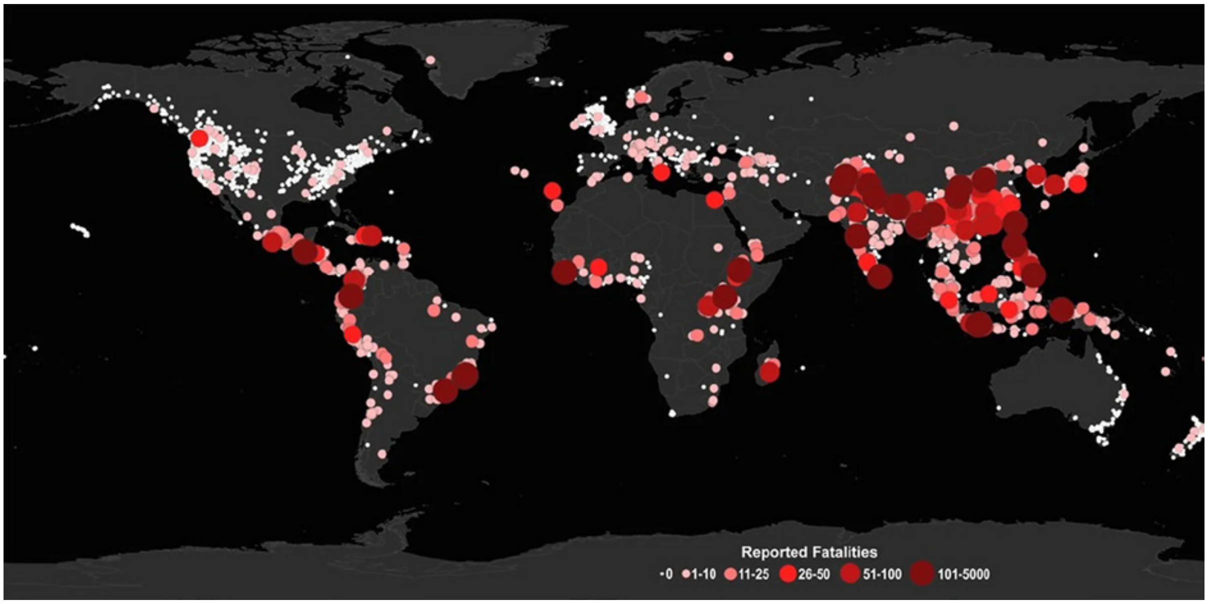


Figure 1. The distribution of reported fatalities from 10,804 rainfall-triggered landslides in NASA's Global Landslide Catalog (GLC) from 2007 to 2017. *White dots* represent incidents with zero reported fatalities. *Pink to red dots* represent incidents in the range of 1–5000 fatalities. The NASA Landslides team, based primarily out of NASA's Goddard Space Flight Center (GSFC), develops the Global Landslide Catalog and LHASA with support from the NASA's Disasters program. **Figure credit:** NASA Scientific Visualization Studio

the conditions surrounding them, allowing it to recognize patterns that indicate a landslide is likely.

The result is a landslide *nowcast*—a map showing the potential of rainfall-triggered landslides occurring for any given region within the past day. This map of hazard likelihood can help agencies and officials rapidly assess areas where the current landslide risk is high. It can also give disaster response teams critical information on where a landslide may have occurred so they can investigate and deploy life-saving resources—see **Photo 2**.

Photo 2. In 2021, a 7.2 magnitude earthquake struck Haiti, triggering a series of landslides across the country. Landslides can destroy infrastructure and impede the movement of people and life-saving aid. **Photo credit:** United Nations World Food Programme

Generating landslide nowcasts is merely the first step. To be truly effective, vulnerable communities must receive the data in a way that is accessible and easy to integrate into existing disaster management plans. That's where the Pacific Disaster Center comes in.

PDC is an applied research center managed by the University of Hawaii, and it shares NASA's goal to reduce global disaster risk through innovative uses of science and technology. Its flagship DisasterAWARE software provides early warnings and risk assessment tools for 18 types of natural hazards and supports decision-making by a wide range of disaster management agencies, local governments, and humanitarian organizations. Prominent users include the International Federation of Red Cross and Red Crescent Societies (IFRC), the United Nations Office for the Coordination of Humanitarian Affairs (UN OCHA), and the World Food Programme (WFP).

"The close pairing of our organizations and use of PDC's DisasterAWARE platform for early warning has been a special recipe for success in getting life-saving information into the hands of decision-makers and communities around the world," said **Chris Chiesa** [Pacific Disaster Center—*Deputy Executive Director*].

The collaboration with PDC brings NASA's landslide tool to tens of thousands of existing DisasterAWARE users, dramatically increasing LHASA's reach and effectiveness. Chiesa notes that teams in El Salvador, Honduras, and the Dominican Republic have already begun using these new capabilities to assess landslide hazards during the 2023 rainy season.

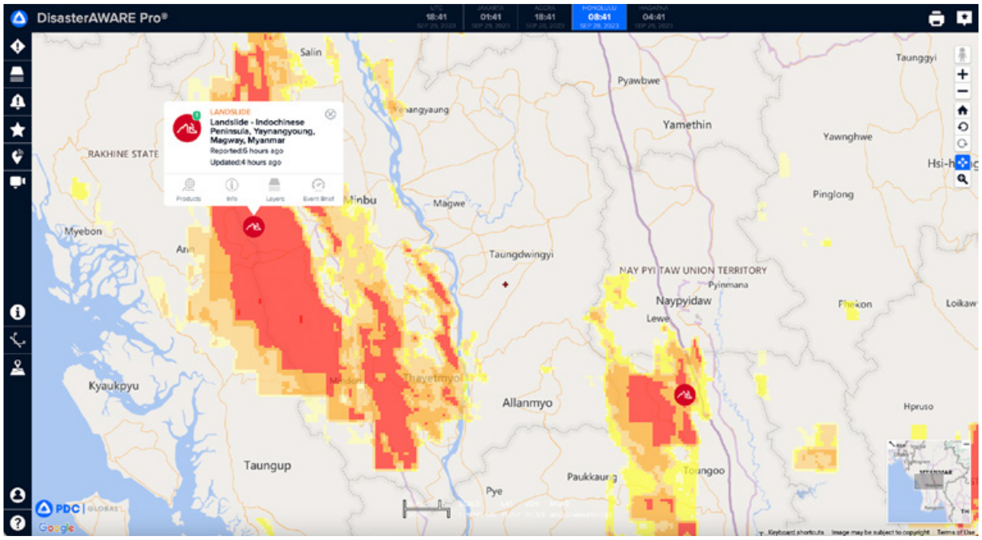


Figure 2. This screenshot from PDC's DisasterAWARE Pro software shows LHASA landslide hazard probabilities for Myanmar in September 2023. *Red* areas indicate the highest risk for landslide occurrence within the past three hours, while *orange* and *yellow* indicate lesser risk. **Figure credit:** Pacific Disaster Center

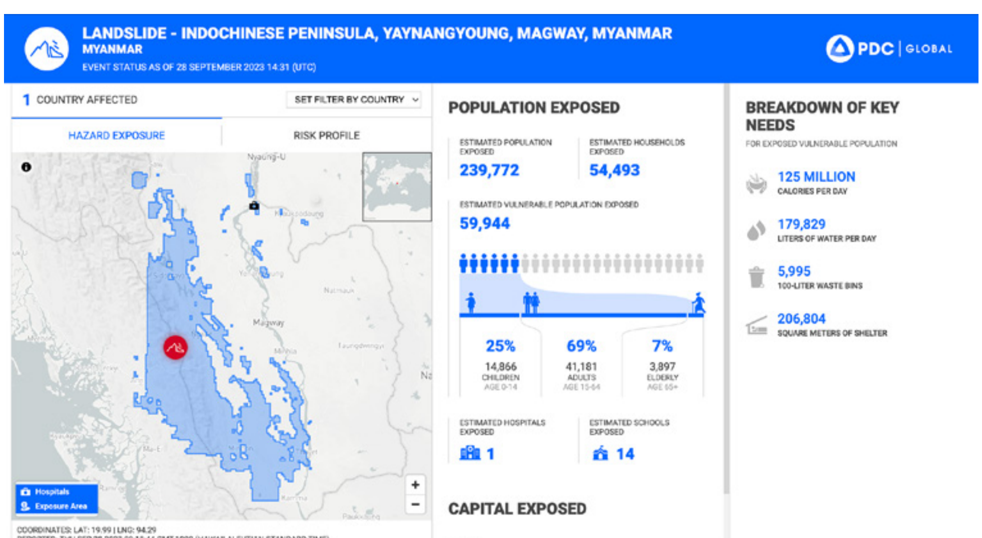
PDC's software ingests and interprets LHASA model data and generates maps of landslide risk severity—see **Figure 2**. It then uses the data to generate landslide hazard alerts for a chosen region that the DisasterAWARE mobile app pushes to users. These alerts give communities critical information on potential hazards, enabling them to take protective measures.

DisasterAWARE also creates comprehensive regional risk reports that estimate the number of people and infrastructure exposed to a disaster—focusing specifically on things like bridges, roads, and hospitals that could complicate relief efforts when damaged—see **Figure 3**. This information is critical for allowing decision-makers to effectively deploy resources to the areas that need them most.

This effort between NASA and the PDC builds upon a history of fruitful cooperation between the organizations. In 2022, they deployed a **NASA global flood modeling tool** to enhance DisasterAWARE's flood early-warning capabilities. They have also shared data and expertise during multiple disasters, including **Hurricane Iota in 2020**, the **2021 earthquake in Haiti**, and the devastating August **2023 wildfires in Maui**, PDC's base of operations.

"The LHASA model is all **open-source** and leverages publicly available data from NASA and partners," says **Dalia Kirschbaum** [NASA's Goddard Space Flight Center (GSFC)—*NASA Landslides Team Lead* and *Director of Earth Sciences at GSFC*]. "This enables other researchers and disaster response communities to adapt the framework to regional or local applications and further awareness at scales relevant to their decision-making needs." Kirschbaum and her team were recently **awarded** the prestigious NASA Software of the Year award for their work developing LHASA. ■

Figure 3. DisasterAWARE landslide risk report for Myanmar, showing estimated population, infrastructure, and capital exposure to landslide risk, as well as the community's needs. **Figure credit:** Pacific Disaster Center



International Ocean Satellite Monitors How El Niño Is Shaping Up

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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*.

Not all **El Niño** events are created equal. Their impacts vary widely, and satellites like the U.S.-European **Sentinel-6 Michael Freilich** help anticipate those impacts on a global scale by tracking changes in sea surface height in the Pacific Ocean. Sentinel-6 Michael Freilich—launched in November 2020 and named after former NASA Earth Science Division Director **Michael Freilich**—is the latest satellite contributing to a 30-year sea level record that researchers are using to compare this year's El Niño with those of the past.

Water expands as it warms, so sea levels tend to be higher in places with warmer water. El Niños are characterized by higher-than-normal sea levels and warmer-than-average ocean temperatures along the equatorial Pacific. These conditions can then propagate poleward along the western coasts of the Americas. El Niños can bring wetter conditions to the U.S. Southwest and drought to regions in the western Pacific, including Indonesia. This year's El Niño is still developing, but researchers are looking to the recent past for clues as to how it is shaping up.

There have been two extreme El Niño events in the past 30 years: the first from 1997 to 1998 and the second from 2015 to 2016. Both caused shifts in global air and ocean temperatures, atmospheric wind and rainfall patterns, and sea level. The maps to the right—see **Figure**—show sea levels in the Pacific Ocean during early October of 1997, 2015, and 2023, with higher-than-average ocean heights in *red* and *white*, and lower-than-average heights in *blue* and *purple*. Sentinel-6 Michael Freilich captured the 2023 data, the TOPEX/Poseidon satellite collected data for the 1997 image, and Jason-2 gathered data for the 2015 map.

By October 1997 and 2015, large areas of the central and eastern Pacific had sea levels more than 7 in (18 cm) higher than normal. This year, sea levels are about 2–3 inches (5–8 cm) higher than average and over a smaller area compared to the 1997 and 2015 events. Both of the past El Niños reached peak strength in late November or early December, so this year's event may still intensify.[1]

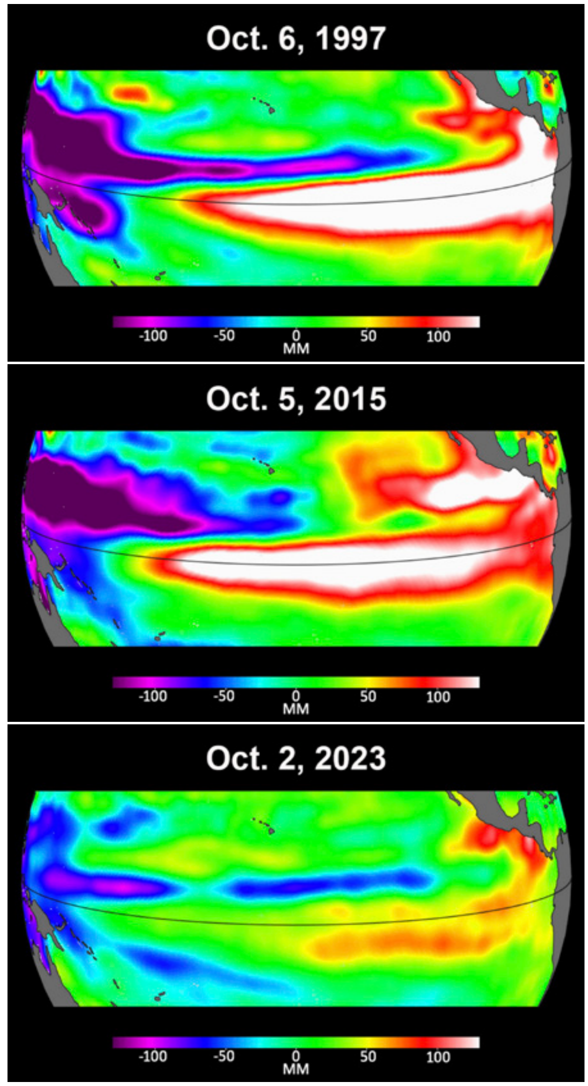

Figure. The maps above show sea levels in the Pacific Ocean during early October of 1997, 2015, and 2023, in the run up to El Niño events. Higher-than-average ocean heights appear *red* and *white*, and lower-than-average heights are in *blue* and *purple*. **Figure credit:** NASA/JPL

"Every El Niño is a little bit different," said **Josh Willis** [NASA's Jet Propulsion Laboratory (JPL)—*Sentinel-6 Michael Freilich Project Scientist*]. "This one seems modest compared to the big events, but it could still give us a wet winter here in the Southwest U.S. if conditions are right." ■

[1] UPDATE: According to the **January 11 El Niño Advisory** issued by the National Oceanic and Atmospheric Administration's (NOAA) Climate Prediction Center, the current El Niño is playing out as was predicted in November. When all is said and done, it is likely to go down as one of the strongest El Niños recorded in the past 70 years.

NASA Earth Science in the News

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

New Space Station Sensor Can Reveal Hidden Greenhouse Gas Polluters, November 17, 2023, *scientificamerican.com*. An instrument on the International Space Station (ISS) is proving its mettle at spotting plumes of greenhouse gases that are altering Earth's climate. The sensor, called **Earth Surface Mineral Dust Source Investigation** (EMIT), was delivered to the space station in the summer of 2022. Its main purpose is to determine how dust in the atmosphere affects Earth's climate.[1] However, it turns out this capability also allows EMIT to gather highly detailed observations of previously unknown plumes of the key greenhouse gases methane (CH_4) and carbon dioxide (CO_2), according to a **new study** that analyzed the instrument's first 30 days of data. Scientists hope the ability to **pinpoint emission sources** can be a valuable tool in tackling the climate crisis as greenhouse gases reach ever higher concentrations in the atmosphere. The EMIT sensor is valuable because it pairs the precision of technology such as high-resolution, airplane-mounted instruments with the wide coverage of satellites. "With a lot of the previous methods, you might get a sense of what's happening in a broad region or a city, but it's not always possible to attribute the emissions to, let's say, this part of the city, this power plant, this landfill," says **John Lin** [University of Utah], who was not involved in the study. "That type of attribution becomes quite useful, especially if we think about ways to reduce these emissions." EMIT has already spent more than a year watching Earth. Those observations prioritized monitoring dust, however, so the instrument thus far has focused on particularly dusty regions such as northern Africa and Central Asia. As a secondary task, greenhouse gas sensing has taken a back seat; in the scant time available to date for emissions work, the team prioritized studying CH_4 over CO_2 because **methane sources** aren't as well understood—see **Figure 1**. "That might change if NASA continues the mission into the new year and beyond," says **Robert Green** [NASA's Jet Propulsion Laboratory (JPL)—*EMIT Principal Investigator* and *study co-author*].

[1] To view some exciting results from EMIT's primary mission, see *The Editor's Corner* of this issue, page 1.

Although the new research covers only 30 days of observations, Green says that EMIT has observed more than 830 greenhouse gas plumes to date. The EMIT

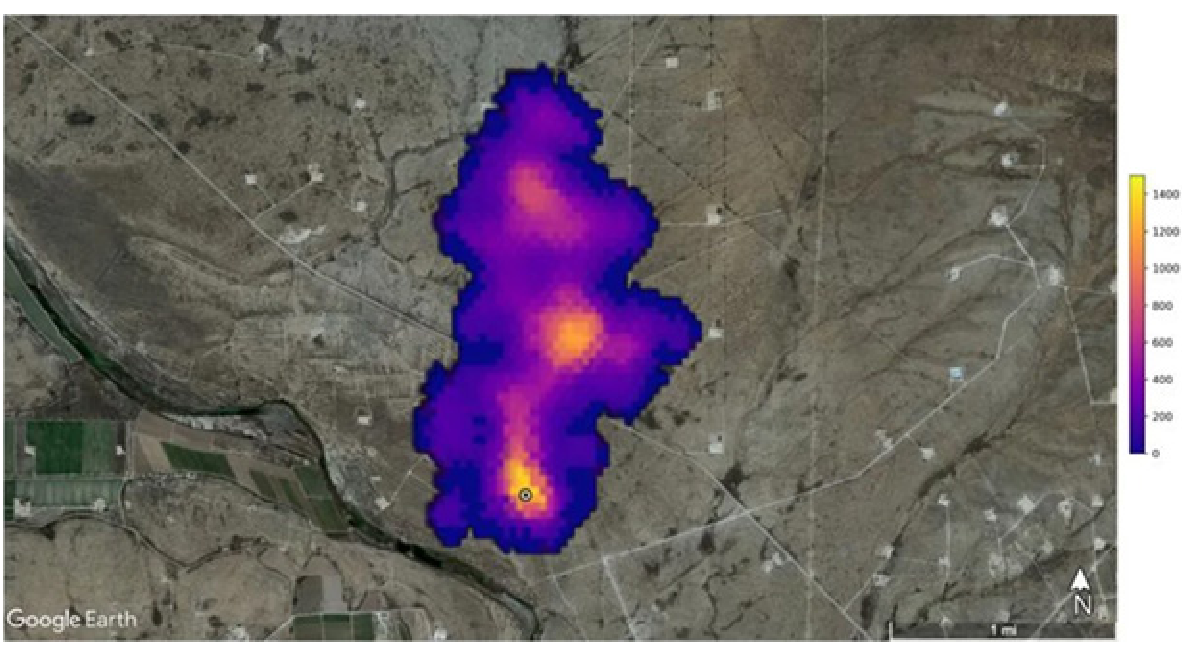

Figure. Data from NASA's Earth Surface Mineral Dust Source Investigation (EMIT) sensor show a two-mile-long methane plume in New Mexico. **Figure credit:** NASA/JPL team is posting its data publicly and says some voluntary emissions reduction measures have already been taken because of its work. Even if EMIT is limited in its ability to inventory greenhouse gases, its data could still help countries meet 2021's global methane-reduction pledge, which aims to reduce emissions by at least 30% of 2020's levels by 2030. **Methane** is a more powerful greenhouse gas on a per-molecule basis than carbon dioxide and is also shorter-lived in the atmosphere, making it an appealing target for short-term action. "If we could really reduce methane emissions, we could reduce the rate of warming in the next few decades," Lin says. ■

NASA Warns El Niño could bring 'Extra Flooding' this Winter, November 8, 2023, *ktla.com*. New analysis from NASA shows that major flooding in cities along the West Coast could become a serious problem if a strong El Niño develops this winter, as is **widely expected**. El Niño happens every few years and is characterized by sea levels that are higher than normal and above average temperatures in the Pacific along the equator. The impacts vary depending on the strength and duration of each event.[2] NASA's sea level change science team analyzed data and determined that this year's predicted prolonged moderate to strong El Niño is likely to lead to increase in high-tide flooding in area along the Pacific coast. Cities like San Diego, CA, and Seattle, WA could experience "ten-year flood events." Meanwhile, in the Southern Hemisphere, Ecuador could see up to three of these same flood events. Currently, these historic flood events are unlikely to happen during non-El Niño years, but that could change by the 2030s due to rising sea levels and climate change. These areas could experience "ten-year floods" annually, with or without El Niño, NASA says. Missions that monitor sea levels, including the **Surface Water and Ocean Topography** (SWOT) satellite and **Sentinel-6 Michael Freilich**, help to monitor El Niños in the near term. SWOT, in particular, collects data on sea levels right up to the coast—see **Figure 2**—which can help to improve sea level rise projections.

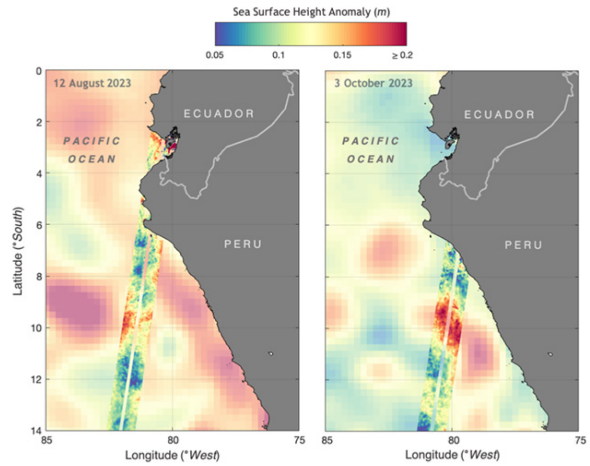

Figure 2. Data from the SWOT satellite shows *sea level anomalies*—how much higher or lower sea levels are compared to the average height—off the coast of Ecuador and Peru on August 12, 2023, and October 3, 2023. The data indicates the development of an El Niño along the west coast of the Americas. **Figure credit:** NASA/JPL

That kind of information could aid policymakers and planners in preparing their communities for rising seas in the next decades. NASA says the extent of flooding in specific cities depends on multiple factors, including a region's terrain and the location of homes and infrastructure near the ocean. "As climate change accelerates, some cities will see flooding five to 10 times more often," said **Nadya Vinogradova Shiffer** [NASA Headquarters—*SWOT Program Scientist and Director of NASA's Ocean Physics Program*]. "SWOT will keep watch on these changes to ensure coastal communities are not caught off guard." ■

NASA PACE Mission is Set to Unravel How Smoke, Dust Shape Earth's Climate, December 13, 2023, *indiatoday.in*. NASA's **Plankton, Aerosol, Cloud, ocean Ecosystem** (PACE) mission is poised to revolutionize our understanding of Earth's atmosphere and oceans. Slated for launch in early 2024, PACE will deploy two advanced polarimeters to study the intricate dance between light, aerosols, and clouds, offering unprecedented insights into their impact on climate and air quality. *Aerosols*—tiny airborne particles such as sea salt, smoke, dust, and pollutants—play a critical role in shaping our planet's climate. They scatter and absorb sunlight, influencing how much solar energy reaches Earth's surface. Moreover, these particles are central to cloud formation, affecting weather patterns and climate dynamics. However, the complexity of their interactions with light has made it challenging for scientists to fully grasp their effects. Enter PACE, with its cutting-edge instruments—including the **Hyper-Angular Rainbow Polarimeter #2** (HARP2) and **Spectro-polarimeter for Planetary Exploration one** (SPEXone). These two polarimeters will make independent measurements of the polarization of light—a property invisible to the naked eye but crucial for understanding the size, composition, and concentration of atmospheric particles—see **Visualization** on page 43. "If you saw the world through eyes that could see polarization, like our sensors can, you would see rainbows everywhere," said **Kirk Knobelspiesse** [NASA's Goddard Space Flight Center (GSFC)—*PACE Mission Polarimetry Lead*].

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[2] See News story on page 37 for more how the evolution of the current El Niño compares to other strong events in the past.

Visualization. Two instruments on NASA's upcoming PACE satellite mission will look at aerosols and clouds—the A and C in the mission's name—to help scientists learn more about their characteristics and interactions in Earth's systems. **Visualization credit:** NASA/ Ryan Fitzgibbons and Kel Elkins

The HARP2 and SPEXone duo of polarimeters promises to deliver a comprehensive view of our atmosphere with an accuracy never before achieved—particularly when combined with PACE's other instrument, the **Ocean Color Instrument**. The significance of PACE extends beyond scientific curiosity. The mission's data will have practical applications, such as improving air quality forecasts and informing policy decisions. As PACE orbits Earth every two days, it will amass vast amounts of data on aerosols and clouds, filling gaps in current climate models with up-to-date measurements. This will enable more accurate predictions of climate trends and help reduce uncertainties in climate science. "I'm hoping to help gather the data that will reduce model uncertainty and help us make better predictions for how we expect our climate to play out in the next decades and centuries," Knobelspiesse said. ■

Earth Science Meeting and Workshop Calendar

NASA Community

May 14–16, 2024
CERES Science Team Meeting
POC: **norman.g.loeb@nasa.gov**
Hampton, VA

Global Science Community

January 28–February 1, 2024
American Meteorological Society (AMS) Annual Meeting
Baltimore, MD

February 13–16, 2024
American Geophysical Union (AGU) Chapman Conference
Honolulu, HI

February 18–23, 2024
Ocean Sciences Meeting
New Orleans, LA

February 26–28, 2024
Third Workshop of the International Cloud Working Group (ICWG)
Darmstadt, Germany

February 28–March 2, 2024
Commodity Classic
Houston, TX

April 14–19, 2024
European Geosciences Union (EGU) General Assembly
Vienna, Austria

May 17–22, 2024
American Thoracic Society International Conference
San Diego, CA

May 26–31, 2024
Japan Geoscience Union (JpGU) Annual Meeting
Chiba, Japan

May 29–31, 2024
Second Workshop on Remote Sensing in Oxygen Absorption Bands
De Bilt, The Netherlands

June 17–21, 2024
International Radiation Symposium
Hangzhou, China

June 23–28, 2024
Asia Oceania Geosciences Society (AOGS) Annual Meeting
Pyeongchang-gun, Gangwon-do, South Korea

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