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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EOS Senior Project Scientist

This summer, NASA's **Tropospheric Emissions: Monitoring of Pollution** (TEMPO) mission released its first images, a significant step forward in its mission to improve air quality monitoring across greater North America. Positioned in geostationary orbit, TEMPO uses an ultraviolet/visible spectrometer to scan across the continent hourly—from Mexico City to the Canadian oil sands, and from the Atlantic to the Pacific—capturing daytime measurements of major air pollutants, e.g., ozone, nitrogen dioxide, sulfur dioxide, and formaldehyde. The high-resolution and frequency of images provide precise data on the origin, concentration, and movement of pollution over time, exceeding the capabilities of current ground-based monitoring systems.

TEMPO data will help scientists understand gas pollutant emissions and related processes, as well as their health impacts and aid in the creation of air pollution maps at the *neighborhood scale*, improving understanding of air quality disparities within a community. The science mission is a collaboration between NASA and the Smithsonian Astrophysical Observatory (SAO) in Cambridge, MA.

The first pollution maps released by NASA from the mission show concentrations of nitrogen dioxide gas from pollution around cities and major transportation arteries of North America—e.g., the **Figure** *below* focuses on the *East Coast megalopolis*—the heavily populated area surrounding the major cities along the I-95 corridor (a major highway) on the U.S. East Coast.

Ball Aerospace built the instrument for TEMPO, which was then integrated with the Maxar-built Intelsat 40e. Since launch, teams from NASA, Ball Aerospace, and SAO have been checking and calibrating the satellite's systems and components. The instrument began full operations in October, collecting hourly daytime scans, the first instrument to observe pollution over North America in this way. The mission will provide new insights for public health officials, atmospheric researchers, and members of the public looking to monitor and improve the quality of the air we breathe. To read more about TEMPO's first light images, turn to page 54 of this issue.

Congratulations to **Kelly Chance** [SAO—*TEMPO Principal Investigator*] and the entire TEMPO team on achieving "first light" for this exciting new mission.

Turning from the newest NASA remote-sensing capability to one of the longest legacy satellite programs, the **Landsat Program** celebrated its semicentennial in 2022 with a variety of events throughout the year organized to commemorate five decades of continuous Earth

continued on page 2

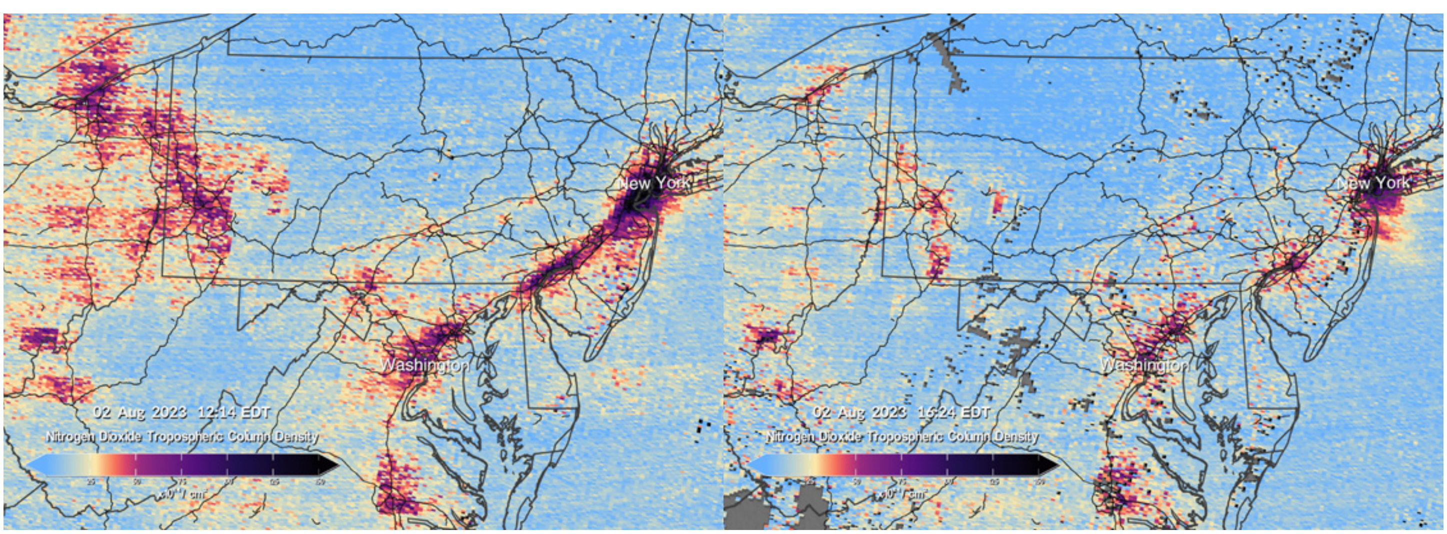

Figure 1. This pair of images shows nitrogen dioxide (NO_2) levels over the Washington, DC/Philadelphia/New York region at 12:14 PM Eastern Standard Time (EST) [*left*] and 4:24 PM EST [*right*] on August 2, 2023, as measured by TEMPO. **Figure credit:** Kel Elkins, Trent Schindler, and Cindy Starr/NASA's Scientific Visualization Studio (SVS)

In This Issue

observations from space via a long-running partnership between NASA and the U.S. Geological Survey (USGS). This year marks the end of the current incarnation of the **Landsat Science Team** (LST). The **2018–2023 LST** focused on ensuring that data from the newest Landsat mission, **Landsat 9**, was integrated into the Landsat archive and that future Landsat science requirements (e.g., **Landsat Next**) reflected evolving user needs while maintaining observational continuity with past and current Landsat missions. The current LST also maintained Landsat compatibility with international and commercial data to enable new applications.

The LST typically meets twice a year. These meetings provide a public forum for discussing the state and future of the Landsat Program. The gatherings are also opportunities for the LST to recognize those who have made significant contributions to the Landsat program's success. To read an update on the recent activities of the 2018–2023 LST and highlights from the most recent meetings of the LST, turn to page 38 of this issue.

From its inception in 1959, NASA has had a mandate to study the planets—including the one we call home. In the same speech that is remembered for President John F. Kennedy's challenge for the U.S, to "[go] to the Moon in this decade," he also specifically mentioned developing a "satellite system for worldwide weather observations." Clearly, studies of the environment are now—and have always been—an important part of the agency's activities.

To promote closer examination of the historical connection between NASA and the environment, the NASA History Office and Georgetown University (GU) organized a two-day symposium from September 29–30, 2022 at the Intercultural Center (ICC) on the GU campus in Washington, with a virtual participation option. The Symposium's primary objective was to analyze the long history of NASA's exploration of—and impact upon—*environments* (broadly construed), with a particular emphasis on biological systems.

While NASA is known for its studies of environments on other worlds and celestial objects, no environment is more familiar—and impactful to our lives—than that of our home planet Earth. NASA's Earth Science program grew out of this desire to better understand the current state of the environment of the place we call home and how it may change in the future. The success of this endeavor rests on the shoulders of countless remarkable individuals who have contributed their talent and commitment to NASA over the years and helped to shape its success. These individual stories are important to chronicle as woven together, they form a larger tapestry that is the Story of NASA Earth Science.

Snippets of some of those Earth science stories were shared at the "History of NASA and the Environment" symposium in September 2022. The current issue contains an article that gives a detailed summary of the content from the symposium that were deemed most relevant to the audience of this newsletter. Included among the presenters are numerous prominent names from the history of NASA's Earth Science program—and the Earth Observing System in particular—as well as some who are currently involved in NASA Earth science endeavors. Turn to page 03 of this issue to read the article, which also includes links to *YouTube* videos and unabridged notes that cover the entire two-day event.

On a related note, in this issue, we honor the lives of two exceptional figures in NASA Earth science history who passed away recently: **Nancy Maynard**, and **Joe McNeal**. To read about their impactful lives and careers at NASA, turn to page 50 in this issue. ■

Earth Science Highlights from the History of NASA and the Environment Symposium

Alan B. Ward, NASA's Goddard Space Flight Center/Global Science & Technology Inc., alan.b.ward@nasa.gov

Introduction

"NASA is called the space agency, but in a broader sense, we could be called an environmental agency . . . Virtually everything we do, manned or unmanned, science or applications, helps in some practical way to improve the environment of our planet and helps us understand the forces that affect it."
—**NASA Administrator James Fletcher**, *Remarks to Congress*, March 1973

From its inception, NASA has had a mandate to study the planets and stars—including the planet we call home. In the present day, an entire division of NASA's Science Mission Directorate is dedicated to studies of Earth's environment and climate. A growing fleet of Earth observing satellites study our home planet and how it is changing over time. Satellite observations are supplemented by observations from aircraft and ground-based instruments, as well as the output from numerical modeling of various aspects of the Earth system. Clearly, studies of the environment are now—and have always been—an important part of the agency's activities.

To promote closer examination of the historical connection between NASA and the environment, the NASA History Office and Georgetown University (GU) organized a two-day symposium, from September 29–30, 2022, at the Intercultural Center (ICC) on the campus of GU in Washington, DC, with virtual participation via prerecorded presentations and hybrid discussion sessions (i.e., in-person and via *Zoom*). The Symposium's primary objective was to analyze the long history of NASA's exploration of—and impact upon—*environments* (broadly construed), with particular emphasis on effects by and on biological systems, wherever found.

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The planning committee for the symposium consisted of the following individuals:

- **Brian Odom** [NASA's Marshall Space Flight Center (MSFC)—*Acting Director of NASA's History Office*];
- **Neil Maher** [New Jersey Institute of Technology (NJIT)/Rutgers University (RU), Newark—*Professor of History*];
- **Dagomar Degroot** [GU—*Professor of History*]; and
- **Teasel Muir–Harmony** [Smithsonian's National Air and Space Museum (NASM)—*Historian of Science and Technology* and *Curator of the Apollo Collection*].

Symposium Overview

The **Symposium agenda** was organized into two livestream tracks (Track A and Track B) with six sessions each: three on the first day and three on the second. Each session included ~10-minute presentations from 3–5 panelists followed by a period of discussion with the moderator asking the first question and then leading a free-flowing conversation among moderator, panelists, and in-person Symposium participants that followed. See **Table** on page 4 for details.

The remainder of this article summarizes the highlights of the Symposium presentations most relevant to the context and audience of *The Earth Observer*. (Most of these summaries were reviewed by the presenter prior to publication.) To view the full presentations—including those not covered in this report—refer to the livestream

Track recording links included in the Table below.[1] In addition, **unabridged Symposium notes**—taken during the meeting by the author and his colleague at NASA's Goddard Space Flight Center (GSFC)/Global Science & Technology Inc. (GST), **Doug Bennett**, and enhanced afterwards by the author—are also available. While raw, they provide an outline of the entire Symposium and formed the basis for the narrative summaries included in this report.

Space precludes including the full Discussion summaries here. However, one or more excerpts relevant to the audience of *The Earth Observer* from each have been chosen to give a representative sampling of the full discussion at the Symposium. The reader is encouraged to consult the unabridged Symposium notes and listen to the online recordings to glean their full context.[2]

In addition to the six Symposium sessions and Discussions, there was a Keynote Panel Conversation that took place on the evening of the first day at GU's Healey Family Student Center Social Room. To read an excerpt from this conversation, see "Keynote Panel Conversation" on page 5.

The remainder of this article summarizes the highlights of the Symposium presentations most relevant to the context and audience of The Earth Observer.

Table. List of sessions during the two-day *History of NASA and the Environment Symposium*. There were two livestream tracks spread over two days; each track had six sessions. Four URL links are provided in the table below—one for each track and each day. The timestamp included in each row is to aide in locating the approximate start of individual sessions on the livestream video recording. Sessions listed in **boldface type** are those deemed most directly relevant to the audience of *The Earth Observer*—and thus are described in more detail in the report that follows.

Title	Session	Timestamp	Moderator [Affiliation]
Track A, Day 1			
Pollution: Global and Local	1A	0:00:07	**Neil Maher** [NJIT/RU]
Extreme Environments and Cabin Ecologies	2A	1:37:10	**Melinda Baldwin** [University of Maryland, College Park]
Space Contamination and Astrobiology	3A	4:19:24	**Lisa Ruth Rand** [California Institute of Technology]
Track A, Day 2			
Cultural Meanings and Changing Perceptions	4A	0:04:30	**Teasel Muir–Harmony** [NASM]
Photography, Gender, and Science	5A	1:57:43	**Neil Maher** filled in for **Margaret Weitekamp** [NASM]
Publicity, Promotion, and Education	6A	4:37:57	**Martin Collins** [NASM, emeritus]
Track B, Day 1			
Climate Change, Weather, and Atmospheres I	1B	0:00:00	**Dagomar Degroot** [GU]
Monitoring the Earth Environment	2B	1:47:40	**Jennifer Levasseur** [NASM]
Building the Earth Observing System Infrastructure	3B	4:26:55	**Roger Launius** [Launius Historical Services]
Track B, Day 2			
Deep Space and Deep History	4B	0:07:12	**Joshua Howe** [Reed College]
Climate Change, Weather, and Atmospheres II	5B	1:51:40	**Mike Hankins** [NASM]
Colonization, Geoengineering, and Astrofuturism	6B	4:35:26	**Matt Shindell** [NASM]

[1] There were two interruptions in the livestream of Session 1A that resulted in parts of two presentations not being fully recorded. The unabridged Symposium notes reflect those interruptions.
[2] The Discussions that followed the Sessions not described in this report were not summarized in the unabridged Symposium notes. However, they can be listened to on the livestream recordings.

Keynote Panel Conversation

As described in the Symposium agenda, "This Keynote Panel Conversation brought together historians and scientists to discuss a broad range of issues related to the history of NASA and the environment. The goal was not only to explore areas of possible interdisciplinary collaboration regarding NASA's long history of collecting environmental data, but also to brainstorm how such data might benefit equitably all forms of life on Earth." Keynote Panel participants included:

- **John McNeill** [Georgetown University (GU)—*Environmental Historian, moderator*];
- **Dagomar Degroot** [GU—*Associate Professor of Environmental History*];
- **Kelsey Herndon** [NASA's Marshall Space Flight Center, NASA SERVIR—*Research Scientist*];
- **Joshua Howe** [Reed College—*Associate Professor of History and Environmental Studies*];
- **Neil Maher** [New Jersey Institute of Technology/Rutgers University, Newark—*Professor of History*]; and
- **Nancy Searby** [NASA Headquarters (HQ)—*Program Manager for Earth Science Applied Science Capacity Building*].

The evening opened with **Pete Mara** [GU, Earth Commons—*Professor of History*], who gave a brief promotional "recruitment" for the Environment and Sustainability programs at GU. Over the remainder of the approximately two-hour event, the moderator asked the panelists a series of questions covering a wide range of topics. He allowed the panelists to answer first and then opened the floor to the audience for discussion—which, in some cases, included follow-up questions. As with other discussions described in this article, space limitations preclude presenting the full dialogue, so included here are two Earth-science-relevant snippets.

The moderator (**John McNeill**) commented that NASA has been a driving force in creating, collecting, and analyzing data that address climate change. He asked: *How successful has NASA been at publicizing these data and looming environmental changes?*

Nancy Searby agreed that while NASA is certainly a key contributor in making Earth System information readily available to a wide constituency, other government agencies [e.g., National Oceanic and Atmospheric Administration (NOAA) and U.S. Geological Survey (USGS)] and international space agencies are similarly involved. One important difference is that NASA looks holistically at the Earth System—whereas NOAA and USGS tend to focus on specific aspects of the system—each in accordance with their agency mandates. She said that while vast amounts of NASA data are available, it is not always easy to access and use. Searby works in *Earth Science capacity building*, which seeks to bridge the gap between Earth Science information and a *user's* ability to readily access, understand, and utilize that information to solve "real-life" problems. She also mentioned that the basic premise of the planned **Earth Information Center** (EIC) is to take NASA's holistic understanding of the Earth System and make it more readily available and easier to use by a wider community of users—but she added that it is definitely still a work in progress.[3]

"This Keynote Panel Conversation brought together historians and scientists to discuss a broad range of issues related to the history of NASA and the environment. The goal was not only to explore areas of possible interdisciplinary collaboration regarding NASA's long history of collecting environmental data, but also to brainstorm how such data might benefit equitably all forms of life on Earth."
—Symposium Agenda

[3] **UPDATE:** On June 21, 2023, the EIC officially opened, including a physical space at NASA HQ and an online presence. To learn more about the opening of the EIC and its plans, see **A New Way to Explore Climate Data: NASA Opens the Earth Information Center**, in the May–June 2023 issue of *The Earth Observer* [**Volume 35**, **Issue 3**, pp, 24–25].

Joshua Howe added that NASA was integral in creating the concept of *Earth System Science* (i.e., studying Earth as a system of systems). The study of Earth's systems has been part of NASA's mission from its inception, but the practice of Earth System Science more fully emerged in the mid-1980s. However, NASA tends to think of climate change *globally* (see further discussion below), so important regional issues may not be emphasized.

Kelsey Herndon countered that although NASA does tend to focus on global observations the agency is also taking active steps to be place oriented (i.e., to expand its focus on local phenomena). For example, NASA uses its resources to communicate with various communities about climate science through social media, workshops and symposia, training (e.g., **Applied Remote Sensing Training Program**, or ARSET), and educational resources (e.g., **Global Learning and Observations to benefit the Environment**, or GLOBE), websites (e.g., ***The Earth Observatory***), and other publications (e.g., ***The Earth Observer*** newsletter). Also, the capacity-building component that Nancy Searby mentioned earlier includes her work with SERVIR, which helps people in low- and middle-income countries to learn to use data for specific applications.

*[**Nancy Searby**] said that while vast amounts of NASA data are available, it is not always easy to access and use. [She] works in Earth Science capacity building, which seeks to bridge the gap between Earth Science information and a user's ability to readily access, understand, and utilize that information to solve "real-life" problems.*

There was an audience question which got back to the issue of *scale*, i.e., local vs. global coverage. The ensuing conversation led to the notion of accessing data specific to a person's ZIP code (i.e., neighborhood level) and whether NASA had that capability.

Dagomar Degroot said that local and global go together. For example, climate change is inherently a local problem, but also impacts us globally. His observation was that, in general, NOAA is good at local observations while NASA is good at global observations. He also said that NASA has done a good job making model outputs more accessible and intelligible to users.

Neil Maher replied that NASA creates effective narratives around the science. However, he noted that the "average citizen" does not always feel included in those narratives. For example, he said that for the people in Newark, NJ, (where Maher lives and works) climate change is not their biggest concern. What does concern them are possible environmental toxins in their neighborhood (e.g., drinking water). Maher explained that they would do their own form of "citizen science" to collect data. If they do turn to outside data sources, more often than not they turn to the U.S. Environmental Protection Agency (EPA)—because they provide localized data on pollutants. EPA data allows Maher's students to literally look up environmental pollution data for their ZIP code.

While NASA does not yet acquire or provide such precision data, **Nancy Searby** said that just yesterday this exact topic of conversation came up at the **Equity Action Plan Stakeholders Town Hall** she attended. (This hybrid meeting took place at NASA HQ on September 28, 2022; it was geared toward those who are actively supporting and serving underserved and underrepresented communities.) Someone taking part in the virtual meeting asked: *Does NASA have climate data at the ZIP code level—the way EPA does with pollution data?* The answer is "Not yet." However, this is clearly the direction NASA intends to move in the future with its data distribution.[4] She again mentioned the EIC and said that it aspires to think both locally and globally.

A video of the **full Keynote Panel Conversation** is available for viewing and the full dialogue is captured in the unabridged Symposium notes.

[4] For example, see page 1 of "The Editor's Corner" in this issue to read about and view "first light" images from NASA's **TEMPO** mission. Data from TEMPO will aid in the creation of air quality maps at the neighborhood scale. Also see related News Story on page 54 of this issue for more details.

Summary of Earth Science Related Symposium Presentations

The most relevant Symposium Sessions to the context of *The Earth Observer* were sessions 1B–5B, and 6A. A link to the appropriate livestream track is included after each presentation title. Also, for ease of reference there is a timestamp to the approximate start of the presentation.

Note that this article is not intended to provide a deep exploration of the material presented at the Symposium nor an in-depth history of the topics, but rather to give a sense of the sessions with emphasis on their connection to NASA's Earth Science activities.

Session 1B. Climate Change, Weather, and Atmospheres I

Dagomar Degroot [GU] was the moderator for this session. Three of the four presentations in this session were related to Earth science topics and are summarized in detail. In the fourth, **Andrew Ross** [GU] discussed "An American Atmosphere: Missile Testing, Military Expansionism, and the Origins of the U.S. Standard Upper Atmosphere, 1946–1952" (**Track 1, Day 1**, 00:14:12). He described the creation of first *Standard Atmosphere* (using data from high-altitude V2 Rocket launches conducted at White Sands, NM, after World War II) and how the data were used more for military purposes, extending *verticality*—the ability of aircraft to navigate the upper atmosphere—and thus extended the global reach of the U.S. military in the post-World War II era.

"In geophysics you have all the aspects of discovery, of exploration, travel, excitement, you know—nothing more exciting than watching a rocket blow up with your instrument onboard, except when your rocket actually flies and makes it up to the mesosphere and you get measurements from it. And that's the most exciting thing. I found it's such a diverse world in geophysics—especially exploration geophysics, because where else, in what other field can you get a ride on a hurricane hunter aircraft at wave-top heights into a Category 2 hurricane but in geophysics? Or where can you get a launch from a secret Soviet [intercontinental ballistic missile (ICBM)] base and be present at the launch? I mean this is excitement!"
—Arlin Krueger

Anna Amramina [NASM] discussed "Their Last Bow: NASA's Involvement in the U.S.–Soviet Environmental Research" (**Track 1, Day 1**, 00:02:12). She explained that the U.S. and USSR were adversaries in the Cold War—yet they collaborated and entered science–technical agreements at the same time, including the now-famous "handshake in space" during the 1975 Apollo–Soyuz mission. Earth science received benefits, too: studies of the ozone hole led to NASA partnering with the Soviets on Meteor–3/Total Ozone Monitoring Spectrometer (TOMS)—discussed below.

NASA had launched the first TOMS on Nimbus-7 in 1978,[5] ultimately deciding to partner with the Soviets for a follow on. A launch from Plesetsk Cosmodrome in the Russian north would fill in data gaps resulting from the Nimbus-7/TOMS launch from Vandenberg Air Force Base in California. Although international tensions made this a fraught agreement, the unlikely collaboration was accomplished under the auspices of the Agreement on Cooperation in the Field of Environmental Protection, overseen by the Soviet Hydrometeorological Survey (or Hydromet), negotiated at the 1972 Moscow Summit. She mentioned the role that **Arlin Krueger**, **Charles Cote**, **John Loiacono**, and **Mike Foreman** [all at NASA's Goddard Space Flight Center (GSFC)] at the time] played, as well as that of **Vyacheslav Khattatov** [Central Aerological Observatory, *Russia*] in bringing this last cooperation between the U.S. and the USSR to fruition.

She noted that many important scientific papers came out of this U.S.–Soviet collaboration—and that data from TOMS provided important input to the first report of the **Intergovernmental Panel on Climate Change** (IPCC).

In a sense, the U.S.–Soviet competition that began with Sputnik in 1958 had now come back to full cooperation on Meteor/TOMS in 1991—ironically on the "eve" of the Soviet collapse. She ended by showing lyrics of a song composed by the U.S. and Soviet researchers during this collaborative effort—see *To 16 TOMS* on page 8.

[5] To learn more about the Nimbus program, including Nimbus-7, see **Nimbus Celebrates Fifty Years**, in the March–April 2015 issue of *The Earth Observer* [**Volume 27**, **Issue 2**, pp. 18–31].

To 16 TOMS

This little ditty was composed by the researchers during the U.S.–Soviet Meteor/TOMS collaboration. The melody is the same as the verses of **Sixteen Tons** by **Tennessee Ernie Ford**.

Some say a scientist is made out of mud. But we know he's made out of muscle and blood. Muscle and blood and skin and bone. A back that's weak and a mind that's strong.

We write protocol and what do we get. Editorial comments and nyct, nyct, nyct. Our bosses say finish or else we can't go. We owe ourselves that damned protocol.

We left from the hotel; the sun didn't shine. We picked our pencils and sharpened our minds. We wrote twenty-seven pages of protocol. And our bosses said, "Why bless your soul."

We returned the next day; it began to snow. The travel and progress was really quite slow. Then we broke for coffee, Farita, and tea. And resolved our problems with great certainty.

Edward Goldstein [Independent Scholar, Former NASA Speech Writer from 2002–2009] discussed "The Development of NASA's Earth Science Program and its Role in Climate Change" (**Track 1, Day 1**, *00:24:46*). He acknowledged **Dixon Butler** [NASA HQ, *emeritus*] in the audience as an advisor on his doctoral work at George Washington University (GWU), which is the basis for his remarks today. He quipped that, "Dixon has probably forgotten more about NASA Earth Science than he ever knew."

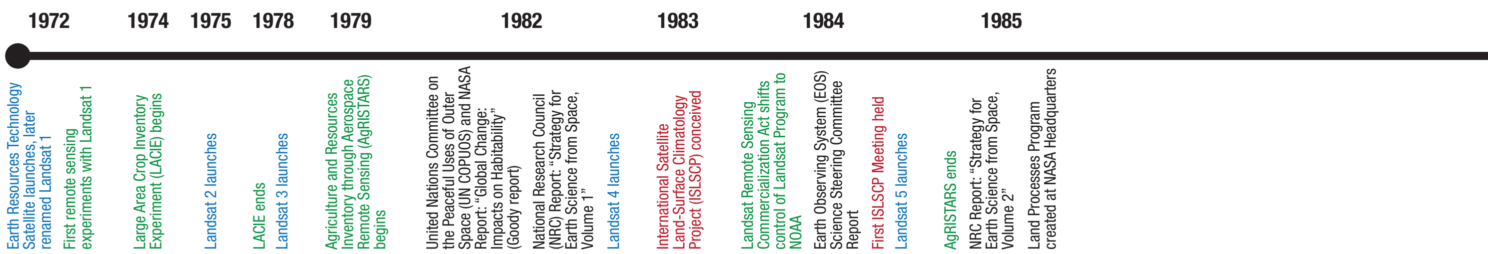
*NASA's Earth Science story is an important one to chronicle. As NASA Speechwriter, [**Edward Goldstein**] got to be close to NASA's Earth Science Program—including the Earth Observing System (EOS)—as it unfolded.*

NASA's Earth Science story is an important one to chronicle.[6] As NASA Speechwriter, Goldstein got to be close to NASA's Earth Science Program—including the Earth Observing System (EOS)—as it unfolded. Meanwhile, as a historian he has studied the history of how it evolved—to learn more see Timeline of Important Dates in Landsat/EOS History: 1972–2004 on pages 8–11, *bottom*). He reviewed the components of the program, as well as the human element—teaching a generation of

[6] *The Earth Observer* newsletter was established in March 1989—in an era before the Internet was widespread—to report history as it unfolded—and also to chronicle that history. Though the style and content are vastly different than when it began, it has kept that focus ever since. As an example, between 2008 and 2011 *The Earth Observer* published a series of "Perspectives on EOS" articles, each written by an author—including several who either participated in or are mentioned in this Symposium—who had unique perspective and insight one or more aspects of the EOS program. The articles were later compiled into a **Perspectives on EOS Special Edition**. Taken together these articles tell the story of EOS—from the point of view of people who lived it.

Timeline of Important Dates in Landsat/EOS History: 1972–2004

The following is a list of some important dates in the history of Landsat and EOS. While far from comprehensive, this timeline [*continued on the next three pages*] references numerous events and activities mentioned in the summaries included in this article, and thus may be a helpful reference. Also included on the timeline are some key dates in Land Surface Climatology history that are mentioned in the presentations by **Bob Murphy** and **Compton Tucker** in Session 2B.



Color Code for Events: Key NASA Environmental/Earth Observing System Meetings, Reports, Reviews, and Events • Key Landsat Historical Dates/Field Experiments
Landsat/EOS Flagship Satellite Launches • International Satellite Land-Surface Climatology Project (ISLSCP) Meeting or Field Campaigns • Impactful Events from Broader NASA History

researchers to think of Earth as a system of interrelated systems, whereas they were used to sticking to individual disciplines.

Goldstein mentioned **James Van Allen**'s key role in providing impetus for the International Geophysical Year of 1958—and intentionally focusing on collecting observations of Earth. Furthermore the launch of Sputnik that same year by America's Cold War adversary, Russia, galvanized public interest in space exploration. In 1961, **U.S. President John F. Kennedy** gave a speech to Congress in which he challenged the nation to "go to the Moon in this decade," but also called for developing a "satellite system for worldwide weather observations."

Goldstein said that there has been a longstanding symbiosis between human space flight issues and planetary programs beginning in the 1970s, such as when concern arose that chlorine released into the atmosphere from the exhaust of the solid rocket booster for the proposed Space Shuttle might harm the ozone layer. NASA's Ozone Research Program took shape under the direction of **NASA Administrator James Fletcher**, who was instrumental in NASA's shift toward studying environmental impacts—eventually including climate change.

Goldstein described the contribution **Jim Hansen** [NASA's Goddard Institute of Space Studies (GISS)] brought to these efforts. Hansen's essential thesis was: "If you change ozone, you change the climate." Hansen became director of GISS in 1981 and shifted the GISS focus towards climate change. He and his GISS colleagues developed the first Global Circulation Model using satellite, airborne, and ground data. This model was the first to make a connection between human carbon dioxide (CO_2) emissions and warming temperature. Hansen went on to later testify to Congress in 1988 that he was "99% certain that climate is warming as result of human activity," and took his thesis to the public. Goldstein opined that Hansen's "going public" with this conversation was an *inflection point* that changed the policy debate on climate.

Goldstein reflected that early NASA Earth Science leaders—like **Dixon Butler**, former Science Program Manager at NASA HQ and **Shelby Tilford**, who became Acting Associate Administrator of NASA's Office of Mission to Planet Earth (MTPE)—were wise to realize that NASA couldn't address the climate issue alone. He added that (as Butler explains in his presentation in Session 3B) NASA was quite innovative in getting the larger scientific community involved. He noted the role of **Francis Bretherton**, a mathematician at University of Wisconsin, Madison, in creating a comprehensive plan (summarized in the now famous *Bretherton Diagram*—see **Figure 1** on page 10) that helped people visualize the idea of studying Earth as a system of interrelated systems—now known as *Earth system science*—and served as a framework to implement Tilford's vision that subsequently became MTPE, later renamed EOS.

Goldstein said that NASA's original EOS concepts suffered from gigantism. While the program began with concepts of huge platforms with multiple instruments (which **NASA Administrator Dan Goldin** had at one point referred to as "Battlestar Galactica"), the system ultimately became three midsized missions supplemented by

1986

- Loss of Space Shuttle *Challenger*
- NRC Report: "Earth System Science: Overview" (Bretherton report, Part I)
- Hydrologic Atmospheric Pilot Experiment–Modelisation du Bilan Hydrique (HAPEX–MoBilHy) in Western Niger (Africa)

1987

- EOS Science Steering Committee Report
- First ISLSCP Field Experiment (FIFE)'87 on the Konza Preserve in Kansas

1988

- NRC Report: "Earth System Science: A Closer View" (Bretherton report, Part II)
- EOS Polar Platform (known as EOS A) Contract awarded
- EOS Announcement of Opportunity (AO) issued
- NRC Report: "Mission to Planet Earth" (MTPE)
- NRC Report: "Our Changing Planet: A U.S. Strategy for Global Change Research"

1989

- EOS AO proposal selections announced
- FIFE'89 again on the Konza Preserve

1990

- NRC Report: "The U.S. Global Change Research Program"
- EOS–Investigators Working Group recommends EOS-A payload complement
- EOS *New Start* approved by Congress (Fiscal Year 1991)
- Global Change Research Act (Public Law (PL) 101-606)
- Report of the Advisory Committee on the Future of U.S. Space Programs (Augustine)—post Challenger
- HAPEX–Sahel

1991

- EOS Engineering Review Committee Report (Frieman)
- Restructuring of EOS program ($17B to $11B)

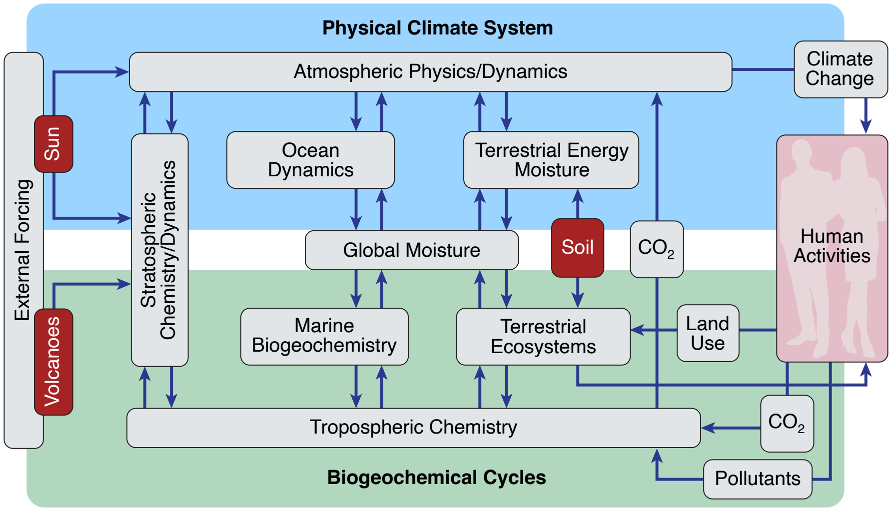


Figure 1. This is a simplified form of the so-called *Bretherton diagram*, which is a helpful tool for visualizing the concept of *Earth system science*, or studying the Earth as a system of interrelated systems. The idea is that a change in any system can impact all the others, and that all must be studied together to understand the Earth's environment and how it might be changing. **Figure credit:** *Content:* NRC Report: "Earth System Science, Overview" (1986); *Design:* Mike Marosy/ NASA/GST

smaller missions with far more flexibility (e.g., from constellation flying) that are the basis of EOS as it exists today.[7]

Tanya Harrison [Planet Labs (Planet), Public Benefit Corporation (PBC), *recorded*] discussed "NASA's Legacy and the Birth of the Commercial Earth Observation Sector: Inspiration and Partnerships for a Better Understanding of the Earth System" (**Track 1, Day 1**, *00:35:33*). She explained that NASA has a longstanding legacy of expertise and excellence in delivering global remote sensing for commercial application. This legacy has spawned a diverse commercial sector, of which Planet is part.

Two of Planet's founders—**Will Marshall** and **Chris Boshuizen**—started their work at the Small Spacecraft Office at NASA's Ames Research Center (ARC), collaborating on a project—PhoneSat—as a test of using commercial off-the-shelf (COTS) parts in space to demonstrate that technology that was specifically designed for a space environment could function in low Earth orbit (LEO). This success became the inspiration for founding Planet with fellow ARC researcher, **Robbie Schingler**.

Harrison explained that NASA's data are critical to Planet's imaging pipeline and data fusion efforts, citing several NASA sources (e.g., the **Moderate Resolution Imaging Spectroradiometer** (MODIS) on EOS **Terra** and **Aqua** platforms, **Hyperion** on the former **Earth Observing–1** mission, and the NASA–U.S. Geological Survey **Landsat** missions) and data from the European Space Agency's (ESA) Copernicus **Sentinel-2** mission. Planet leverages the best of both Earth observing worlds (i.e., NASA's and ESA's extensive and exquisitely calibrated time series of data are combined with the agility of the commercial sector to create applications for the data).

[7] In 2011 **Ghassem Asrar**, former Deputy Administrator for NASA's Earth Science Division, shared his perspective on the evolution of the EOS flight hardware concepts in **The Enduring Legacy of the Earth Observing System, Part II: Creating a Global Observing System—Challenges and Opportunities**, in *The Earth Observer: Perspectives on EOS Special Edition*, pp. 62–72.

1992
- Remote Sensing Policy Act (PL 102-555) assigns management of Landsat 7 to NASA and Department of Defense (DoD)
- Rescoping of EOS program ($11B to $8B)

1993
- Earth Observing System Data and Information Systems (EOSDIS) Core System contract signed
- NRC Report: "Review of EOSDIS" (Zraket committee)
- Boreal Ecosystem–Atmosphere Study (BOREAS) Preparatory experiments in Canada
- Landsat 6 launch failure

1994
- Restructuring of Landsat Program Management (DoD withdraws and NOAA takes over)
- Rebaselining of EOS ($8B to $7.25B)

1995
- Reshaping of EOS
- House of Representatives budget resolution calling for $2.7B (over five years) reduction in MTPE

1996
- NOAA pulls out of Landsat 7 program; U.S. Geological Survey (USGS) steps up as operator
- Fiscal Year 1996 budget approved—without the $2.7B reduction to the EOS budget
- BOREAS, with two study sites in Canada

1997
- MTPE Biennial Review proposes new approach to implementing the EOS 2nd series*
- MTPE renamed Earth Science Enterprise (ESE)

*The EOS 2nd (and 3rd) series were ultimately cancelled completely. The three EOS Flagships never had successors as originally planned. Fortuitously however, all three missions are still operational today.

Earth is experiencing a climate crisis caused by widespread habitat destruction and a global economy recovering from the worst pandemic in a century. NASA and the private sector work together to address these issues. She cited as an example, NASA's **Commercial SmallSat Data Acquisition** (CSDA) program, which was established to identify, evaluate, and acquire data from commercial providers that support NASA's Earth science research and application goals. To date, CSDA has spawned over 100 publications and conference presentations using Planet data.

An example of the synergy between NASA and Planet focused on the impact of climate change in the Arctic. Combining high-frequency (but less calibrated) Planet data with lower-frequency (but "exquisitely calibrated") NASA data—from the **Ice, Clouds, and land Elevation Satellite–2** (ICESat–2)—allowed the researchers to track ice loss.

Harrison concluded by saying that NASA's technological and scientific developments inspire the commercial sector to imagine what else is possible. NASA's extensive, exquisitely calibrated datasets provide a critical baseline for commercial datasets. Programs like CSDA enable broad access to commercial datasets for the research community.

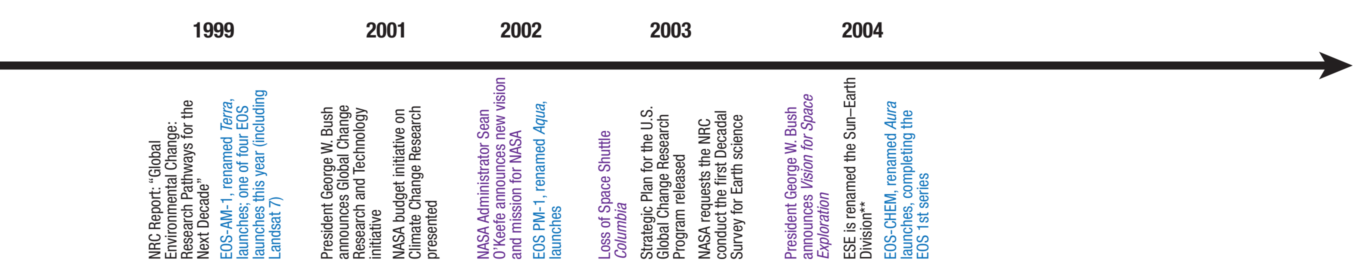
NASA's extensive, exquisitely calibrated datasets provide a critical baseline for commercial datasets.

Session 1B Discussion

Moderator (**Dagomar Degroot**) observed that each presenter in this session highlighted a different agency or several agencies. He was curious about how these different agencies operate in the Earth science realm. The three responses included focus specifically on how NASA operates—from the perspective of a former NASA Historian and speechwriter, and from two EOS pioneers.

Edward Goldstein said that NASA has always been constrained by budget. The EOS budget was downsized numerous times, leading to revisioning, rescoping, and rebaselining. The tri-agency partnership between NASA, NOAA, the Department of Defense (DoD) on the Natonal Polar-orbiting Environmental Satellite System (NPOESS) Preparatory Project [NPP] proved unwieldy.

Bob Murphy, former *head* of NASA's Land Processes Program at NASA Headquarters (HQ), who presented in session 3B, was in the audience for this session. He added that from NASA's perspective, the relationship with NOAA has been beneficial. The DoD runs things differently, as they have institutionally driven requirements that go through a highly formalized process with fewer budget constraints than NASA. NASA has more of an interactive design program, with requirements coming from the larger community as an interactive process involving many stakeholders including those looking to the data for use in applications, such as the U.S. Department of Agriculture (USDA). Murphy's assessment is that the most successful partnership seems to be between NASA and NOAA. Pointedly, he noted that in the end, NPOESS worked. It is now known as the Joint Polar Satellite System (JPSS), which became a NASA–NOAA endeavor, with DoD exiting the NPOESS tri-agency partnership and opting to pursue its own system.



**The Sun–Earth Division was later separated into the Earth Science and Heliophysics Divisions at NASA HQ under NASA's Science Mission Directorate, as they are known today.
Timeline credit: *Content:* See caption (page 8), footnote 10 (page 15), and footnote 15 (page 18); *Design:* Mike Marosy, Dalia Kirshenblat/GSFC/GST

Dixon Butler added that NASA Earth Science initially wanted to work with whomever wanted to participate—but the agency wanted worldwide cooperation, and DoD did not want to do that for military security concerns. So, DoD's role was diminished so that NASA could collaborate globally, although there was—and still is—large DoD investment.

The full discussion can be viewed online (**Track B, Day 1**, *00:44:20*).

Session 2B. Monitoring the Earth Environment

Jennifer Levasseur [NASM] was the moderator for this session.

Christopher Neigh [GSFC—*Landsat 9 Project Scientist*] spoke about "The History of Landsat and the Earth Environment" (**Track B, Day 1**, *01:48:12*). He showed the famous "Earthrise" image taken as the Apollo 8 astronauts were returning from orbiting the Moon in 1968 and noted that this image captured the public's imagination. This photo alone is considered a significant impetus for the modern environmental movement, showing, as it does, a colorful, dynamic Earth floating in the utter blackness of space. The first Earth Day came soon after, in 1970.

"The vast loneliness is awe-inspiring, and it makes you realize just what you have back there on Earth."
*—**Jim Lovell**, Command Module Pilot for NASA's Apollo 8 mission*

The Landsat program is a 50-year partnership between USGS and NASA, in which NASA builds and launches the missions, and USGS manages and distributes the data. Neigh discussed some of the early history that led to the creation of the first Landsat mission—originally called Earth Resources Technology Satellite (ERTS). He mentioned the role that **William Pecora** [USGS—*Director* (1965–1971)] and **Stuart Udall** [U.S. Secretary of Interior (1961–1969)] played in moving the first mission from concept to reality, as well as the pioneering role of **Virginia Norwood** [Hughes Aircraft Company], who designed the Multispectral Scanner (MSS) that flew on Landsat 1-4, and is known as the "Mother of Landsat."[8]

Overall, Neigh summarized the importance of the Landsat program, explaining that the observations from Landsat missions have allowed for major advances in understanding the global land surface beyond what was available from 50 years of prior air photo surveys.

Neigh referenced the book, ***Landsat's Enduring Legacy***, as an excellent summary of Landsat history. He noted that an open access version of this book (available at the link above) has recently been released. While there are many stories in the book that could be highlighted, Neigh chose to focus on a few. He discussed how Landsat transitioned from the analog era to the digital era, developing the ability to process large amounts of Multispectral Scanner (MSS) data—including the important contribution of **Valerie Thomas**, a FORTRAN programmer at the USGS's Earth Resources Observation and Science (EROS) Center, who used MSS datasets to "train" a vegetation model to detect crop types.

Figure 2. Logo for the Large Area Crop Inventory Experiment (LACIE), which ran from 1974–1979, was the first large-scale experiment that used Landsat data, and a precursor for other Landsat investigations.

Neigh also told the story that led to the start of the **Large Area Crop Inventory Experiment** (LACIE), which was initiated in 1974, and was the first Landsat experiment to test large area crop mapping to monitor global agriculture commodities and ultimately to produce production forecasts. This is an interesting case where Cold War politics and the resulting impact on the U.S. economy converged to provide impetus for the development of a new satellite technology. (See **Gemma Cirac Claveras**' presentation in Section 5B for more on the impact of history and politics on satellite technology development.)

Furthermore, Landsat provided the optimal ground resolution and spectral bands of publicly available data to efficiently track land use and document land

[8] Another key name from the history of Landsat is **Darrel Williams**, former Landsat Project Scientist, who in 2008, shared his perspective on the early days of EOS, including his role in both EOS leadership and the development of Landsat. See **Reflections on the Early Days of EOS: "Putting Socks on an Octopus"**, in *The Earth Observer: Perspectives on EOS Special Edition*, pp. 7–9.

change due to climate change, urbanization, drought, and wildfire. In addition, the continuous archive [1972–Present] provides essential land change data and trending information not otherwise available. Landsat represents the world's longest continuously acquired collection of space-based, moderate-resolution land remote-sensing data. Landsat data have led to the most science publications of any Earth observing instrument—the Moderate Resolution Imaging Spectroradiometer (MODIS) in orbit on Terra and Aqua, two EOS-era platforms, runs a distant second—and have been used for myriad societal applications.

Landsat provided the optimal ground resolution and spectral bands of publicly available data to efficiently track land use and document land change due to climate change, urbanization, drought, and wildfire.

Neigh concluded that, with free and open access to data combined with recent advances in cloud computing and the implementation of open science at NASA, William Pecora's original vision for the Landsat program from 50 years ago has been fulfilled.

Laurence Rothman [Center for Astrophysics | Harvard & Smithsonian (CfA),[9] *recorded*] discussed "The **High-Resolution Transmission Molecular Absorption Database** (HITRAN) Project: Molecular Spectroscopic Database Archive for Environmental Monitoring" (**Track B, Day 1**, *02:00:31*). He summarized the history and development of the HITRAN project, which began in the 1960s in response to an Air Force desire to develop a means to detect enemy aircraft by their radiance, while filtering out atmospheric contributions to retrievals. Advances in infrared detectors, computing capabilities, and high-resolution spectrometers converged to allow development of the original proto-HITRAN spectroscopic database, which was publicly released in 1973. Rothman mentioned that the Kitt Peak National Observatory (in Tucson, AZ) was—and continues to be—an important source of HITRAN data.

Rothman described the rapid growth of HITRAN capabilities and use in the last quarter of the twentieth century. He gave three main reasons for growth during this period: continued technological developments that enabled greater scope (e.g., increased spectral range, improved representation of transition states, and more species addressed), the inception of programs that made use of the database (e.g., EOS and later the NASA Planetary Atmospheres program), and the establishment of various collaborative initiatives (e.g., international data assimilation activities, biennial conferences, and journal special issues). More recently, the twenty-first century has seen continued growth in the capabilities of HITRAN and an increase in published results—with increased precision and accuracy—using the database. He said that requirements were driven by the environmental satellite missions of NASA as well as by its Planetary Atmospheres program. It was at this time that the management of HITRAN moved to the CfA. Rothman mentioned, among the more recent advances, the development of a new relational database, expanded validation, *YouTube* tutorials, and an improved website providing easier access to data.

To close, Rothman briefly showed the HITRAN website (see link above) and demonstrated access to one of the most commonly accessed areas: the line-by-line transition parameters of the program. He said that the CfA releases a new HITRAN version every four years; however, interim updates are posted on the website. He ended with a demonstration of HITEMP—the high-temperature analog for HITRAN—in which he showed simulated comparisons to a low-resolution spectra of carbon dioxide in an exoplanet atmosphere obtained by the James Webb Space Telescope.

Robert E. "Bob" Murphy [NASA HQ and GSFC, *emeritus*] described "Land Biosphere Interactions with the Climate System—The Addition of Biology to NASA's Earth Science Program 1983–1996" (**Track B, Day 1**, *02:11:02*). In his presentation, he told the story of how the "rocket science" world of 1970's NASA came to engage

[9] CfA is not an independent legal organization, rather it exists via a memorandum of understanding between Harvard University and the Smithsonian Institution to jointly manage and coordinate the related research activities of the Harvard College Observatory and the Smithsonian Astrophysical Observatory.

with and fund several aspects of the biological sciences in addition to its proven track record in technology and the physical sciences. The programs had supported operational agencies. For example, NASA built and launched weather satellites for NOAA (e.g., Geostationary Operational Environmental Satellites, or GOES) or USGS (Landsat) to operate.

As **Edward Goldstein** earlier explained (in Session 1A), ozone and climate change studies began to change this technically focused paradigm. In the early 1980s climate studies were rapidly growing national priorities. Measurement needs were driven by the data climate modelers needed to improve their representations of the atmosphere. NASA's technology was uniquely positioned to measure these parameters (e.g., temperature profiles, sea surface temperature, cloud properties). Unlike other disciplines, where NASA built the hardware and then handed it off to other agencies for operational use, NASA became involved in the whole process for ozone and climate studies. A new NASA community arose that modeled climate, defined measurement needs, built sensors, and analyzed data—mostly at GSFC, NASA/Jet Propulsion Laboratory (JPL) as well as in the academic community. Murphy emphasized again that this broke the classic model of interagency roles—where NASA did the rocket science, building the spacecraft, and then handing them off to other agencies after launch.

Unlike other disciplines, where NASA built the hardware and then handed it off to other agencies for operational use, NASA became involved in the whole process for ozone and climate studies. A new NASA community arose that modeled climate, defined measurement needs, built sensors, and analyzed data...

This is where biology enters the story. To understand climate, one must consider the impacts of biology. For example, evapotranspiration (ET) is a biological process that controls one-third of the energy budget at Earth's land surface. Yet all weather and climate models at the time treated evapotranspiration as a purely physical process—i.e., evaporation not evapotranspiration—until ~1990. ET is controlled by biological needs of vegetation—not just the physics of the land–atmosphere interface—but classic climate modelers were slow to incorporate this component into models.

Murphy described the first tentative steps toward recognizing the role biology played in climate models, which show up in the "NASA Climate Plan of 1977." Murphy mentioned some of the prominent names associated with this effort: e.g., **Jim Hansen** and **Vince Salomonson** [University of Utah/GSFC, *emeritus*]. ET is mentioned three times; vegetation six times—but this is considered a breakthrough. So, while this plan mentioned ET and its importance, the implicit conclusion was: *"We don't know how to do it."*

The next steps forward came in the 1980s, as awareness of growing environmental problems grew at both the scientific and political level. At this time, NASA began to emphasize its role as a self-contained science agency—and the Office of Management and Budget (OMB) allowed it. **Shelby Tilford**, who was at that time the Upper Atmosphere Research Satellite (UARS) Science Lead, was tapped to lead an integrated Earth Science program at NASA HQ. Tilford quickly consolidated leadership over programs in weather, climate, upper atmosphere, tropospheric chemistry, solid Earth geophysics, oceanography, geology, and agriculture.

The intellectual seeds of how to incorporate biology into climate studies were provided by the newly created International Satellite Land-Surface Climatology Project (ISLSCP), the brainchild of **Ichtiaque Rassool**, who had once been the Chief Scientist for NASA, and had been part of the leadership team for the "NASA Climate Plan of 1977." Working with **Hans Jurgen Bolle** [Freie Universität Berlin, *Germany*], Rassool assembled an international group of remote sensing, meteorological, and ecological experts, to conceptualize a program of field experiments, data analysis, and modeling. Key players included a young British–American scientist named **Piers Sellers**, later to gain fame as a NASA Earth scientist and NASA astronaut (see **Compton Tucker**'s presentation, immediately following this one, for more details), **François Becker** [University of Strasbourg, France], and **Jean Claude André** [Centre National de Recherches Météorologiques (CNRM), France]. ISLSCP developed a unifying intellectual framework that guided national level programs and facilitated international cooperation. Murphy said this was the basis for the initiation of NASA's Land Processes program beginning in 1985—which Murphy led. ISLSCP provided the answer to the question: *What data are needed and how can they be obtained?*

Murphy then described the fortuitous convergence of circumstances that provided impetus for the creation of NASA's Land Sciences Program. One of these was the collapse of the **Agriculture and Resources Inventory Survey Through Aerospace and Remote Sensing** (AgRISTARS) program, which started in 1980 and ended in 1984. In retrospect, for a variety of reasons (e.g., reliance on statistics instead of developing the necessary physics, insufficient revisit time, and too much high spatial resolution data to process), NASA realized that Landsat was manifestly not the right sensor for the job AgRISTARS sought to do. It would be several decades before the science and technology advanced sufficiently to accomplish the goals of AgRISTARS.

*[**Bob Murphy**] described the fortuitous convergence of circumstances that provided impetus for the creation of NASA's Land Sciences Program.*

However, as has often happened throughout NASA history, one program's loss was another program's gain. The AgRISTARS remnants were "absorbed into" NASA's Earth Science program. In 1985 Murphy took leadership of the Land Processes program (under **Shelby Tilford**). He soon hired NASA's first ecologist (**Diane Wickland**) and a hydrologist/agricultural engineer (**Ghassem Asrar**)—both of whom rose to senior management positions at NASA HQ. Under Murphy, the Land Processes Program established rigorous peer-review processes, which had not existed previously. The program also initiated a number of field campaigns following the ISLSCP framework and over time broadened their scope to support global carbon cycle and ecological issues—e.g., HAPEX–MOBILHY (1986—France, U.S.), FIFE (1987, 1989—U.S., Canada), HAPEX-Sahel (1991—France, Niger, U.K., U.S.), BOREAS (1994, 1998—U.S., Canada).[10] Murphy ended by noting that six of the original 29 EOS Interdisciplinary Science (IDS) investigators (which **Jack Kaye** discusses in Session 3B) involved biospheric processes and land–atmosphere interactions.

Compton J. Tucker [GSFC] spoke about "Realistic Exchanges of Water, Energy, and Carbon Between Land and Atmosphere: The Legacy of Piers Sellers: Meteorologist, Astronaut, Advocate for Earth Science, and Humorist" (**Track B, Day 1**, *02:24:11*). **Piers Sellers** revolutionized land-surface modeling by including many elements of biospheric processes in the modeling. To further cement this newly arising approach, Tucker then took attendees back to the "Dawn of Climate Modeling," which (as **Bob Murphy** described) did not include realistic models of biology.[11] Sellers' work built on the shoulders of **Jule Charney** [Massachusetts Institute of Technology (MIT)] and **Yale Mintz** [University of California, Los Angeles (UCLA), and later GSFC]—who personally recruited Sellers to GSFC as a postdoctoral fellow in 1982.

For more detail, Tucker explained that the atmosphere is well-mixed and changes on shorter timescales than land (longer) or oceans (longest). This is why measuring geophysical parameters applied in a quantitative way, based upon physics is so important for land studies. He mentioned that Sellers and **Ichtiaque Rassool** (whom **Bob Murphy** mentioned as the organizer of ISLSCP) realized that an intermediate source of data between satellites and ground was needed. That source would turn out to be aircraft data, which would allow measuring the fluxes of water, carbon, and methane between land surface and the lower atmosphere. Sellers realized that integrated field programs (or *campaigns*) were key. Examples include FIFE and BOREAS (mentioned

[10] To learn more about the campaigns mentioned in this sentence—including what the acronyms mean—and the period in NASA history that **Bob Murphy** and **Compton Tucker** describe, see **Reflections on FIFE and BOREAS: Historical Perspective and Meeting Summary**, in the January–February 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 1**, pp. 6–23]. **Piers Sellers** gave opening remarks at this meeting—in one of his last public appearances (see pp. 12–13). **NOTE:** The FIFE–BOREAS meeting summary has a timeline on page 13 that was the source for most of the Landsat and land surface history events included on the timeline graphic in this article—see bottom of pp. 8–11.

[11] In 2009, **Piers Sellers** offered his unique perspective on the events Murphy and Tucker describe. See **Reflections on the Early Days of EOS: A Biased and Unexpurgated History**, in *The Earth Observer: Perspectives on EOS Special Edition*, pp. 14–18.

in Murphy's presentation), both of which used aircraft to bridge the gap between ground-based studies and satellite data.

Tucker said that Sellers always loved flying and adventure [e.g., see quote on this page] so it was hardly a surprise when in 1996, Sellers left GSFC to become a NASA Astronaut, eventually flying on three Shuttle missions [Space Transport System (STS)-112, -121, and -132]. Altogether he compiled 42 spacewalking hours (roughly equivalent to 25 orbits). Tucker added that Sellers' prior Earth science experience gave him unique perspective when he viewed the Earth from space. He truly earned his nickname: *the human satellite*.

In 2011, with the Shuttle program ending, Sellers returned to GSFC, where he worked in senior management until he passed away in 2016. Sellers was a great spokesperson for the Earth in general—and for NASA Earth Science specifically—and he loved to give interviews. Tucker noted that Sellers seemed as comfortable speaking to Congress as he was speaking to children—and that he especially loved to speak to kids.

When summarizing the characteristics that made Sellers such an exceptional human being, Tucker included kindness, wit, intelligence—and monkey business! Even when facing painful, incurable pancreatic cancer—and knowing the odds were stacked against him—Sellers chose to stay optimistic, hopeful—and humorous. He had that same attitude toward his life's work, as he continued to work toward the "salvation" of the planet until he passed away. Sellers said that unlike the Italian generals of World War II who "led from behind," he preferred to "lead from the front." He had his share of "clashes" with NASA HQ over his ideas, but he never backed down from them—and he *always* kept his sense of humor.

Session 2B Discussion

The context for these comments was a question from the moderator (**Jennifer Levasseur**) about the importance of public messaging in science communication, as science results are not always easy for the public to digest. How important is it to have a figure with a strong public identity (e.g., Piers Sellers) with whom the public can relate?

Compton Tucker remembered that Sellers would have early morning meetings with **Mike Freilich**, former Earth Science Division director at NASA HQ. While they were friends, Freilich could be quite "frank" at times when he didn't agree with someone. Tucker remembered one occasion when Freilich responded negatively to something that Sellers said. Sellers' quick response was something to the effect of: *Mike, I've studied it, I've observed it from space. I think I know.*

The discussion of "spokesperson for the public" triggered a long-ago memory for **Dixon Butler**. He remembered a *CBS Evening News* (with **Walter Cronkite**) segment from the 1970s in which **Michael MeElroy**, a professor at Harvard University, explained the concept of *timescales* to the American public comprehensively in a 45-second soundbite. Butler also mentioned the example of **Carl Sagan**, concluding that having someone who is both well-educated (Professor at Harvard and Cornell Universities) and engaging to communicate science to the public is a real asset. **Bob Murphy** agreed that having a public face is important—even essential. He agreed that Carl Sagan is a well-known example, as was Sellers. Sagan came across to the public as easy going—although in person he wasn't necessarily as approachable. By contrast, Piers Sellers appeared easygoing and comfortably genuine.

In response to a later question, **Dixon Butler** said that Sellers was a tremendous asset as an IDS investigator in 1989. The community felt a strong sense of loss when he chose to become an astronaut. Butler reflected that the sense at the time was, sure, you *could* be another astronaut, but what you bring to NASA Earth science is truly unique. Sellers managed to do both in grand style.

The full discussion can be viewed online (**Track B, Day 1**, *02:36:22*).

Piers loved to fly. He and his four brothers went to boarding school in England from third grade on. Piers did not enjoy the experience. He got his pilot's license before he got his driver's license. Not unlike a scene out of the movie Top Gun, *the first thing Piers did after getting his pilot's license was to "buzz" the boarding school, resulting in his pilot's license being revoked for six months. The school's rector wanted to expel Piers, but his teachers intervened to prevent this. When Piers' pilot's license was reinstated, Piers took his geology professor on a flight to see the white cliffs of Dover from above. When the professor complained the wing was obstructing his view of the cliffs, Piers inverted the aircraft to give professor a better view. His love for flying and "spirit of adventure" served Piers well when he became a NASA Astronaut*

*—**Compton Tucker***

Session 3B: Building the Earth Observing System Architecture

Roger Launius [Launius Historical Services] chaired for this session. Three of the four presentations are summarized in detail here. The fourth was called, "Whose Expertise, Whose Skills? Creating Cross-Disciplinary Approaches to Studying Planetary Environments in the Early Space Age," (**Track B, Day 1**, *04:42:15*), in which **Ron Doel** [Florida State University] discussed how Columbia University's Lamont Geological Survey came to be the primary lab for planetary geophysical investigations in the 1960s. While a fascinating historical analysis that highlights the important role one person—in this case **Frank Press**—can play in influencing environmental history, the details have been omitted to save space.

Jack Kaye [NASA HQ—*Associate Director for Research in the Earth Science Division, recorded*] discussed the "Impact of Earth Observing System Interdisciplinary Science (IDS) Program on the Development of Earth System Science and the Associated NASA Investigator Community" (**Track B, Day 1**, *04:32:08*). He thanked the IDS principal investigators (PI) or team members who responded to his requests for information that he summarized in this presentation.

Kaye gave an overview of the EOS Interdisciplinary Science (IDS) Program, which began in the late 1980s as EOS was ramping up. IDS was created to provide support to *interdisciplinary* teams to work on broad topics of Earth System Science and to "prepare" for the future EOS missions, using existing data as proxies and developing model simulations. IDS proposals were open to the broad Earth System Science community (e.g., academia, NASA centers, and other government agencies' laboratories) and allowed for establishing multidisciplinary, multi-institutional, and—in some cases—multinational teams. Some "international only" or "international-led" teams were selected to engage the international community more broadly. IDS was eventually reformulated following a transition to an era of having EOS satellite information readily available, with relatively large award amounts still allowing for multidisciplinary and multi-institutional funding—but smaller than historical IDS levels and with topics typically changing with each solicitation.[12]

"We have nowhere else to go. We have a very special planet with one climate and we're in this together. Let's solve our climate problem with human ingenuity and focused hard work."
—**Piers Sellers**

Kaye shared an anecdotal synthesis of the results of queries of IDS investigators across a significant breadth of topics. Those integrated teams were essential to the success of investigations. Furthermore, the long and stable funding period was important, as the challenges tackled needed more time than the typical three-year grant cycle and allowed the PIs to invest the time and energy needed for this kind of effort—and to help grow the talent through funding of students, post-docs, and early-career investigators.

Most IDS investigators felt that their teams made important contributions in advancing the science and making the kind of interdisciplinary connections reflected in the Bretherton Diagram and were a central focus of the EOS program. In doing this, they helped set the stage for Earth System Science as assessed by the National Academies in their **Earth Science Decadal Surveys** of **2007** and **2017**.

Kaye concluded by talking about potential next steps. He said that a more thorough investigation of the impact of the IDS experience would require significantly more effort and analysis of historical records (e.g., analysis of publication acknowledgements, citations, and the extent to which IDS supported career development, like students and post-docs), as many IDS investigators developed into strong leaders in several capacities. He also said that the evolution of the broader Earth science community needs to be understood in this context—the move from traditionally "stovepiped" disciplines into multi- and interdisciplinary approaches. Kaye ended by emphasizing that further research into the impact of IDS on Earth System Science would require

[12] One of the author's earliest publications in *The Earth Observer* was a **Summary of the November 2002 Investigators Working Group (IWG) Meeting** that appeared in the January–February 2003 issue [**Volume 15**, **Issue 1**, pp. 3–15]. Although the information is dated—and formatting considerably "looser" than today's standards—it gives an idea of the detailed content of a typical meeting as EOS was ramping up to full operations in the late 1990s and early 2000s.

the cooperation of Earth system scientists and historians (especially historians of science), and possibly public administration professionals.

Dixon Butler [NASA HQ, *emeritus*] discussed. "NASA, EOS, and the Environment," (**Track B, Day 1**, *04:57:35*), in which he gave a ten-minute overview of how EOS came to be—a near-impossible task, but one that met with success in this venue.

In a nutshell, newfound concerns about orbital crowding led to conceiving a single large platform in LEO, studded with instrumentation yet to be determined. It was then that Butler had an epiphany—one that caused such thinking to coalesce around the role(s) of water in Earth system science. This led to an early model based on 19 instruments across three large platforms, referred to as "System Z" (to distinguish it from a parallel effort called "System Omega" marketed toward the Department of Defense).[13] Butler noted that from the beginning there was consensus among those involved that having a data system that could effectively handle the vast amounts of data that would be returned from these proposed Earth observing platforms would be crucial to making it work.

Most IDS investigators felt that their teams made important contributions in advancing the science and making the kind of interdisciplinary connections reflected in the Bretherton Diagram and were a central focus of the EOS program. In doing this, they helped set the stage for Earth System Science as assessed by the National Academies in their Earth Science Decadal Surveys of 2007 and 2017.

Butler realized that the larger Earth science community needed to buy-in—and that they likely would not do so based solely on the conclusions of an all-NASA committee. So, the planning essentially started from scratch with broader interdisciplinary Earth science community involvement. This more diverse group prepared reports, going from a single thin volume for "System Z" to detailed reports on many proposed EOS instruments and the data system. These reports provided the basis for the EOS Announcement of Opportunity (AO) and resulted in the earlier-mentioned cross- and interdisciplinary group, that was now international in scope.

The partners coordinated on the selection of facility instruments and PI instruments—but failed to agree on data policy. At that time, the agreement was that NASA would fly a platform with an afternoon equator crossing time while ESA flew the morning crossing time.

Butler said that EOS AO was—and likely still is—the most complicated NASA AO ever. The EOS review panels lasted for eight weeks. He noted that there was good contractor support for the meeting out in the suburbs. The panelists selected IDS investigators (as discussed earlier by **Jack Kaye**), EOS Instrument investigators, and Facility instrument team members and leaders. The panel decided that data processing would be done at Earth Observing System Data and Information System (EOSDIS) Distributed Active Archive Centers (DAACs) based at organizations where significant applicable expertise was resident. Algorithms would be delivered by PIs and/or instrument teams to the DAACs.[14]

Following these glory days of early EOS, concerns and issues were raised by several organizations, including the DOD, and JPL was dropped from EOS management. Later, Congress reduced the 10-year budget from the $17B promised under the New Start to $11B.[15]

Susan Schoenung [NASA's Ames Research Center] discussed "NASA's Airborne Science Program (ASP) Contributions to Environmental Science" (**Track B, Day 1**,

[13] In 2008, **Dixon Butler** shared his perspective on EOS, which covers his involvement as "System Z" and other details of this period in NASA history. See, **The Early Beginnings of EOS: "System Z" Lays the Groundwork for a Mission to Planet Earth**, in *The Earth Observer: Perspectives on EOS Special Edition*, pp. 10–13.

[14] To learn more about the DAACs and NASA's data infrastructure, see, **Earth Science Data Operations Acquiring, Distributing, and Delivering NASA Data for the Benefit of Society**, in the March–April 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 2**, pp. 4–18].

[15] In 2009, **Greg Williams**, a Senior Policy Analyst in the variously titled Earth science organizations at NASA HQ from 1993–2004, described the series of "Re-Visions" to EOS that took place from 1991–1995 as well as other details of EOS history in **A Washington Parable: EOS in the Context of Mission to Planet Earth**, in *The Earth Observer: Perspectives on EOS Special Edition*, pp. 19–26. **NOTE:** Williams' article has a timeline on page 26 that was the source for the EOS history events included on the timeline graphic in this article—see bottom of pp. 8–11.

05:18:50). She introduced a few of the aircraft that NASA uses, then reviewed the many roles of ASP and its historical context. She noted that aircraft fly in the "gap" between ground-based measurements and those from satellites and can provide a unique vantage point for atmospheric studies. The largest role of Airborne Science is to support Earth observing satellite missions.

Schoenung summarized some of the early history of airborne observation,[16] emphasizing that the success of today's Airborne Science program builds on the vision of those who came before. She explained that the areas where aircraft observations had the earliest impact were on imaging and spectroscopy validation. Focus areas here included land cover studies [e.g., Landsat Thematic Mapper Simulator, Airborne Visible and Infrared Spectrometer (AVIRIS)] and ozone hole science [e.g., Airborne Antarctic Stratospheric Experiment]. Another area of early impact for aircraft observations was in the realm of upper troposphere/lower stratosphere (UTLS) chemistry. The discovery of the ozone hole led to flights (high-altitude ER-2 and lower-altitude DC-8) to measure chlorine chemistry in the Antarctic. Data from these flights were instrumental in providing justification for the Montreal Protocol that banned the production of chlorofluorocarbons in 1987.

...aircraft fly in the "gap" between ground-based measurements and those from satellites and can provide a unique vantage point for atmospheric studies. The largest role of Airborne Science is to support Earth observing satellite missions.

Aircraft observations provide a unique vantage point for observations, particularly in the *tropopause*, where there is a sharp change in the temperature profile of the atmosphere (from lowering with height in the troposphere to rising with height in the stratosphere). This sharp change makes for interesting atmospheric chemistry.

It turns out that high-altitude aircraft (ER-2 and WB-57) are ideally suited for observations at the altitude of the tropopause, with subsequent development of uncrewed aircraft systems (UAS) (e.g., Global Hawk), augmenting these measurements. Initially designed to reach the tropopause, these UAS have proven useful for a wide variety of other observations.

As an example, Schoenung cited the Hurricane and Severe Storm Sentinel (HSS), in which two Global Hawks launched out of Wallops Flight Facility when there were active tropical cyclones in the Atlantic. One flew above the hurricane while the other flew around the storm. She went on to give more examples of recent airborne flights in support of cryospheric and land change research and in validating data from other current and upcoming Earth observing missions.

Session 3B Discussion

Presenter **Christopher Neigh** noted that today's space-based instruments require initial proof of concept on aircraft. He wondered if this was the case for EOS instruments. **Dixon Butler** commented that EOS instruments were most certainly validated. For example, AVIRIS was built to test the High Resolution Imaging Spectrometer EOS (HIRIS), which was originally planned to be part of the EOS-A payload. Ultimately, HIRIS never flew, and the Japanese **Advanced Spaceborne Thermal Emission and Reflection Radiometer** (ASTER) instrument took its place. **Susan Schoenung** mentioned the **MODIS/ASTER Airborne Simulator** [MASTER] simulator (which was not covered in her presentation) was built to validate both ASTER and MODIS data.

The context for the next three responses was a discussion about the importance of developing international partnerships. **Susan Schoenung** said such collaborations are crucial for suborbital campaigns, especially when campaigns are conducted in foreign countries, and **Dixon Butler** noted that NASA worked closely with the Brazilian

[16] To learn more about the history of NASA's Airborne Science program and other details, see **Flying in the "Gap" Between Earth and Space: NASA's Airborne Science Program**, in the September–October 2020 issue of *The Earth Observer* [**Volume 32**, **Issue 5**, pp. 4–14]. A newer **NASA Science Suborbital Platforms lithograph** is available for download; this is a helpful—and more up to date—resource on current NASA suborbital systems including aircraft, uncrewed aircraft systems (UAS), balloons, and even kites.

Space Agency to get permission to do flights over the Amazon. This partnership learned from the experience with ESA, which had earlier tried to negotiate such an agreement—only to literally have their planes turned back when they tried to enter Brazilian airspace. **Jack Kaye** added that for the later Largescale Biosphere experiment in Amazonia (LBA), the Brazilians required each investigating team to have at least one Brazilian on the team. Kaye said that a whole generation of Brazilian researchers got their start in LBA.

The full discussion can be viewed online (**Track B, Day 1**, *05:41:50*).

Session 4B: Deep Space and Deep History

Joshua Howe [Reed College] was the moderator for the four presentations of this session. Although all had at least some connection to Earth science, in the interest of saving space, only the one most relevant to NASA Earth science (addressing SERVIR; see below) is described fully here. See the Agenda for the remaining three.

Kelsey Herndon [MSFC] discussed "Seventeen Years of SERVIR: Applications of Earth Observations to Improve Environmental Decision Making Around the Globe," (**Track B, Day 2**, *00:23:03*). She acknowledged **Daniel Irwin** [MSFC—*SERVIR Global Program Manager* and *Founder*], who couldn't be here today to present. She explained that **SERVIR**, which is the Spanish word for "to serve," is a joint initiative between NASA, the U.S. Agency of International Development (USAID), and leading geospatial organizations in Asia, Africa, and Latin America to address critical challenges in climate change, food security, water and related disasters, land use, and air quality.

Herndon then shared the SERVIR origin story. As frequently happens, a chance meeting led to the development of a new NASA applications program. In the late 1990s **Dan Irwin** had a chance meeting with **Tom Seaver**—a NASA space archaeologist. Irwin's first view of a giant Landsat map made him realize that he'd spent years in the field trying to map out what this single satellite image was showing him. The idea emerged that remote sensing could be used not only for learning about the past but also learning about present. Thus developed SERVIR, originally conceived as "one-stop-shop" for data. A NASA Research, Education and Applications Solution Network (REASON) proposal in 2003 bought in USAID as a partner.

Herndon explained that SERVIR supports projects in more than 50 countries though five regional hubs in the Amazon, West Africa, Eastern and Southern Africa, the Himalayas, and Mekong region, supporting dozens of applications and services. She focused her presentation on two of these services: crop mapping in Kenya and improved severe weather forecasting in Bangladesh. In virtually all cases, SERVIR has provided data that is used in "boots on the ground" applications, with, for example, Kenya now being able to offer crop insurance at lower cost than earlier, owing (in part) to the reduction in data-access costs: five years ago, there were 900 farmers insured against crop loss—today there are over 1.4 million insured farmers. SERVIR also actively recruits women farmers to participate in index-based insurance.

Herndon also discussed the **High Impact Weather Assessment Tool** (HIWAT), which the government of Bangladesh uses to produce actionable warnings ahead of hail, lightning, extreme rainfall, and other hazards. HIWAT forecasts are helping the Bangladesh Meteorological Department and Department of Agricultural Extension put out timely alerts to save lives and property. Alerts are issued based on SERVIR HIWAT forecasts—which will be sent to over 30 million farmers in Bangladesh within the next two months.

Herndon closed by reflecting on "SERVIR Then and Now" in three key areas: open science, compute resources, and capacity building. For open science, SERVIR was originally proposed as a "one stop shop for geospatial data," but now open data abounds and SERVIR focuses on codeveloping and implementing sustained solutions.

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In terms of computing resources, SERVIR was limited to one-off analysis over small areas, but now the SERVIR network can take full advantage of Earth Observation big data to develop solutions for major environmental challenges. Regarding capacity building, SERVIR originally developed solutions and then passed off the results to local partners, hoping to make an impact. Today, SERVIR codevelops demand-driven solutions with regional partners through a long-term commitment to institutional capacity building.

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Session 4B Discussion

The moderator (**Joshua Howe**) mentioned the *paradox of presentism*[17] that refers to the tendency to focus on the era you are analyzing. The past is treated like a "foreign country" where things work differently. All this to say: *One doesn't come to history without some reason for coming.* He asked the panelists about the relationship between *speculation* and *observation* in creating the "new types of knowledge" covered in these presentations? (While all panelists responded, only the answer most relevant to the audience of *The Earth Observer* is included.)

Kelsey Herndon said that at SERVIR, there is an interplay between speculation and observation. We have satellite observations that show us something. We speculate but we don't know until we take observations of the situation on the ground with our partners.

There was a later comment from **Bob Murphy**, in the context of how things get done and that individuals matter. He found the discussion about **Tom Seaver**'s role in the development of SERVIR fascinating. Seaver saw a technology and figured out something that could be done with it—which led to **Dan Irwin** starting SERVIR—which reaches well beyond archaeology. Murphy also mentioned **Shelby Tilford** (discussed in Murphy's presentation in Session 2B) as another example of someone who did this. In Tilford's case, he used discretionary funds to create a Land Processes Program (which Murphy led.)

The full discussion can be viewed online (**Track B, Day 2**, *00:55:53*).

Session 5B: Climate Change Weather and Atmospheres II

Mike Hankins [NASM] moderated this session, which included four sessions, three of which are described in detail here. In the fourth, **Gemma Cirac Claveras** [University of Barcelona, *Spain*, *recorded*] gave an "Introduction to the Project CLIMASAT: Using the History of Satellite Data to Write a History of Climate" (**Track B, Day 2**, *02:09:45*). Her research aims to understand how the historical and political context in Europe in the late 1980s and 1990s influenced the development of three European satellite systems: **Meteosat**, for severe storm data; the **Ocean Topography Experiment** (TOPEX)/Poseidon for sea surface height data; and the **European Remote Sensing Satellite** (ERS) for ozone.

Christopher Hain [MSFC, *recorded*] discussed "NASA's **Short-term Prediction Research and Transition Center** (SPoRT): A Historical Perspective on Transitioning NASA Research into Operations" (**Track B, Day 2**, *01:53:03*). He began by giving the historical perspective, explaining that SPoRT was established in 2002 with a focus on transitioning unique NASA satellite observations and research capabilities to end users to improve short-term operational weather forecasting and decision support.[18] The SPoRT paradigm has been used over the past 20 years to successfully transition 40 satellite datasets and research capabilities to operational users. SPoRT has built and maintained a strong relationship between NASA and NOAA's National Weather Service. SPoRT's user-focused *research-to-operations* and *operations-to-research*

[17] Sam Wineburg uses this term in his 1999 essay, **Historical Thinking and Other Unnatural Acts**.
[18] To learn more about SPoRT see, **Transitioning NASA Earth-observing Satellite Data to the Operational Weather Community**, in the May–June 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 3**, pp. 4–11].

paradigm and applications-based training concepts have been adopted by other groups nationally and internationally.

The SPoRT paradigm has been used over the past 20 years to successfully transition 40 satellite datasets and research capabilities to operational users.

Hain reported that SPoRT served as a GOES-R/JPSS Proving Grounds, using NASA polar-orbiting missions [Terra, Aqua, Suomi National Polar-orbiting Partnership (NPP)] to help prepare users for GOES/JPSS capabilities (Geostationary Lightning Mapper, multispectral composite imagery, hyperspectral infrared soundings), and demonstrate further integration with NASA observations and capabilities. SPoRT team members have authored 46 peer-reviewed journal articles since 2014.

Key to SPoRT success is involvement of stakeholders at all stages of product development. As a result, over the past several years, SPoRT has been broadening its reach and has begun to apply its known research-to-operations paradigm to several new partners that can benefit from the integration of unique NASA satellite observations and research capabilities.

Hain listed the current SPoRT partners and the SPoRT research-to-operations thematic areas, which include tropical meteorology, atmospheric remote sensing, lightning/convection, air quality and human health, land surface remote sensing, and machine learning. He then discussed some specific examples, which can be found in the unabridged Symposium notes.

James "Jim" Garvin [GSFC—*Chief Scientist* (at the time of the meeting), *recorded*] discussed "Topographic Monitoring and Modelling of the Earth's Environment from the 1980s to Present" (**Track B, Day 2**, *02:04:27*) in which he provided a brief summary of the history of laser altimetry. Garvin described it as a story of engineering and science coming together to measure the shape of the Earth at "human scale." The story began in the 1980s at GSFC, with scientists and engineers putting together technology to measure the land at "the scales we walk on," culminating with the first orbital flight of an analog waveform laser altimeter, the Shuttle Laser Altimeter (SLA) mission, on which Garvin was PI. SLA flew on the Space Shuttle *Endeavor* in January 1996 (STS-72). Garvin emphasized that technologies like SLA, developed to study Earth, have been adapted for use in measuring the Moon and other planets (e.g., the **Mars Orbiter Laster Altimeter** (MOLA) mapped Mars from 1999 to 2001).[19]

After his recorded message, Garvin (who was virtually present on the day of the meeting) added that he intended the video to encapsulate a longer story. The history of NASA and climate research is one of establishing boundary conditions. The shape of the land is one of those boundaries—at scales that aren't always accessible. Technologies that are now "standard" had to be invented 40 years ago. He said that techniques are evolving rapidly: what the **Global Ecosystems Dynamics Investigation** (GEDI) can measure over tropical forests and what ICESat-2 can measure over the ice sheets is quite remarkable—and Garvin said, "There is more to come!" New missions are planned to study Earth (e.g., the **NASA–Indian Space Research Organisation (ISRO) Synthetic Aperture Radar**, or NISAR), the Moon (e.g., Artemis), and other worlds (e.g., the **Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging** (DAVINCI) mission to Venus). These new missions and others will add new chapters to NASA's altimetry story.[20]

Timothy Lang [MSFC—*Lightning Imaging Sensor (LIS) on ISS Project Scientist*] discussed the "History of NASA Global Lightning Observations" (**Track B, Day 2**, *02:21:25*). While he did not discuss them in his presentation, he acknowledged up front that other countries are also making lightning observations from space.

[19] Garvin is Principal Investigator for DAVINCI, which is planned for launch in 2029. Its goal is to understand the runaway greenhouse effect on Venus, and the conditions there might be predictive of Earth's future.

[20] To learn more about the story of the development of MOLA—and SLA—see **Chapter One** and **Chapter Two** of the "**Leaders in Lidar**" *YouTube* series produced by GSFC's Scientific Visualization Studio.

Lang reviewed why NASA studies lightning from space. Lightning is a natural hazard—threatening lives, damaging infrastructure, causing wildfires, and posing a risk to NASA launches (e.g., **lightning struck Apollo 12** shortly after launch). Lightning is related to processes within deep convection, and by studying it we learn more about how storms impact Earth's weather and climate. Lightning also produces trace gases—e.g., nitrogen oxides (NO_x)—which modulate ozone levels in the atmosphere. These gases are important for biogeochemical cycles and for regulating Earth's climate. Finally, lightning can go beyond the troposphere (e.g., sprites and halos) and even occurs on other planets.

Most of the remainder of Lang's presentation surveyed the history of quantitative lightning observations from space.[21] Lang also mentioned that suborbital (aircraft) observations played an important role in testing concepts for spaceborne instruments, supporting rocket launches (e.g., continuous ground observations of lightning at Kennedy Space Center), and validating on-orbit observations of lightning. He noted that aircraft observations played a pivotal role in determining the utility of the 777-nm oxygen emission line for detecting lightning during both day and night.

Lang concluded by saying that NASA has produced a multidecadal record of lightning observations from space and looks forward to continuing it into the future. The challenge now is to merge data from different instruments to create continuous time series to allow investigations of climatological trends.

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Session 5B Discussion

In response to a question from the moderator (**Mike Hankins**) about whether science questions or applications drive plans for missions, **Timothy Long** answered that science questions drive these practices. As an example, he mentioned the Earth Science Decadal Survey process where white papers are written, and then a committee evaluates the science. He also said that applications have become increasingly important. More recent missions have considered how data will be used/applied from the initial planning stages—e.g., Early Adopter programs for each mission.

Jim Garvin added that there are cycles of NASA development. He mentioned that there was an Applications Program at NASA HQ as far back as the 1970s—a response to this issue coming up in the 1960s and 70s with Apollo. This led to development of the Applications Program in the 1970s and 80s. So, there has been an attempt to bridge the "gap" between science and applications well before Decadal Surveys. The Mission to Planet Earth infrastructure (what we now know as EOS) was implemented in the 1990s. As we understand more about climate, we realize what fundamental measurements are missing—but we also see feedback loops into societal benefits. He added that the same is true as we look at environments beyond Earth—e.g., Moon, Mars, and Venus.

Christopher Hain said that it is a welcome change to see applications considered from the formulation phase of a mission. Much of NASA Science is now done with applications that will benefit in mind from the beginning. Finding a balance between science and downstream applications is a point of emphasis for NASA. "People need to be able to use data from the beginning," said Hain.

The full discussion can be viewed online (**Track B, Day 2**, *02:33:36*).

Session 6A: Publicity, Promotion, and Education

Martin Collins [NASM] moderated this session; it included four presentations, two of which are more relevant to Earth science and summarized in detail here.

[21] To learn more about this history, see **LIS on ISS: Expanded Global Coverage and Enhanced Applications**, in the May–June 2016 issue of *The Earth Observer* [**Volume 28**, **Issue 3**, pp. 4–14].

Emily Watkins [American University, Graduate Student and recent NASA GSFC intern] discussed "Experiments in Efficacy: NASA Earth Science Video Production Team's Evolving Strategies for Climate and Environmental Communication" (**Track A, Day 2**, *04:40:52*). She began with a discussion of: *Why do we need science communicators?* NASA has always strived to communicate its scientific findings to the public. With the rise of the internet and social media, there is a great deal of information at our fingertips—but not all of it is accurate. There is a need for accurate scientific information to be conveyed in an unbiased manner. Personal opinions and politics can bias our communication and make it untrustworthy.

NASA has always strived to communicate its scientific findings to the public. With the rise of the internet and social media, there is a great deal of information at our fingertips—but not all of it is accurate. There is a need for accurate scientific information to be conveyed in an unbiased manner.

Watkins outlined six steps (questions) for effective science communication:

1. *What's the science?* There are three pillars on the Earth Science team: Current events, scientific visualization pipeline, and input from scientists.

2. *What's the story?* Story is the best way to convey information. Innovative ways to relay information to connect with a wide variety of audiences. This requires quality communicators.

3. *Who's the audience? What's the medium?* Know to whom we speak, and what the requirements are for the medium in which we seek to communicate.

4. *What visualization tools are available?* NASA has a whole archive of videos that can be drawn upon, e.g., data visualizations, animations, archival footage, interview footage.

5. *How successful was the communication?* Collect metrics on engagement (e.g., views on YouTube).

6. *How do we evolve over time?* NASA sticks to science—and science only. However, the communication teams have to adapt to new environments and situations (e.g., COVID).

To give an example of effective communication, Watkins concluded by showing part of the video she produced when she was an intern as GSFC, which discussed the Hunga Tonga–Hunga Haʻapai eruption in 2022 and its global impacts.

Lin Chambers [NASA Headquarters, *recorded*] described "How NASA Engaged Students and the Public Around the World in Observing the Environment to Support NASA Science" (**Track A, Day 2**, *05:21:40*). She described the **Global Learning Observations to Benefit the Environment** (GLOBE) Program, which was included in the NOAA Authorization Act of 1994. It arose from a White House initiative (led by **Vice President Al Gore**) to involve a network of students throughout the world in collecting and sharing environmental data. The goal from the start was to have students participate in real science. NASA's initial role was to develop the visualization system—a state-of-the art system at that time.

Chambers noted that when GLOBE started in 1995, eight U.S. Agencies and Departments, plus the White House, were involved, along with 11 other countries (1995 United Nations Resolution). From its inception GLOBE was a science and education program with international involvement.

Chambers also discussed the **Students' Cloud Observations On-Line** (S'COOL) program, a grassroots effort that began after a conversation with a middle school teacher in late 1996. It aimed to involve students in the study of the effect of clouds on Earth's climate. The first S'COOL observation was made on a clear day, i.e., no clouds to observe. While the students were disappointed, it was a teachable moment to reinforce that "zero is data."

In 2016 S'COOL became the clouds protocol for the GLOBE Program and the first module in a new **GLOBE Observer app**. Citizen scientists and students now take and report data using their mobile device. Chambers showed data from a week before versus the day of the 2017 Total Solar Eclipse, when the path of totality is clearly visible from the concentration of observations—see **Figure 3** on page 26. She concluded by reporting that this month (September 2022) the GLOBE Observer App had its millionth match between ground observations and satellites.[22] GLOBE has helped tremendously not just in bringing Earth science data to the public (students), but in involving them in *bona fide* scientific research.

[GLOBE] arose from a White House initiative (led by ***Vice President Al Gore****) to involve a network of students throughout the world in collecting and sharing environmental data. The goal from the start was to have students participate in real science.*

Session 6A Discussion

A question from the moderator (**Martin Collins**) about science diplomacy led to **Lin Chambers** responding that—in addition to its scientific literacy and research emphasis—GLOBE has an element of science diplomacy. The State Department is a partner and helps negotiate a bilateral agreement with each country involved—127 and counting as of this writing. The **Mosquito Habitat Mapper** was added to GLOBE Observer courtesy of the State Department because the agency wanted to involve local residents in tracking mosquito breeding areas during the Zika virus outbreak in South America (2015–2016). She added that GLOBE has trained hundreds of public health professionals across the Tropics to use this App to identify mosquito breeding habitats, to the benefit of all.

A later question from the moderator about foundational challenges for bilateral agreements prompted Chambers to comment that there was likely a multilateral discussion among the original 11 GLOBE countries that established the framework (she was not involved at that time). Subsequent agreements are basically the same for every nation that joins—but it still can take a long time before they are ready to sign on. A few countries have dropped out because they don't want data from their nation available on a U.S. Government website. Again, the State Department plays a key role in negotiating these agreements.

The full discussion can be viewed online (**Track A**, *5:32:18*).

Conclusion

The *History of NASA and the Environment Symposium* sought to analyze the long history of NASA's interest in, responses to, exploration of, and impact upon environments—as broadly construed. The wide range of presentations across the two tracks and six sessions touched on most—if not all—of these areas. The presentations made it clear that—at base—NASA's environmental activities are the result of interactions between myriad people, at many hierarchical levels. Further, the discussions after each session were often every bit as interesting as the presentations—and added significantly to the overall impact of the Symposium. This deep dive into NASA's activities in this area also demonstrated that there is always room for growth and further development.

The **Keynote Panel Conversation** (held the first evening of the Symposium) was a forum to explore those growing edges. In one of the last questions of the conversation, **John McNeill** [GU—*Keynote Panel Moderator*] said that it has been a good thing to gather scientists and science historians at the same event to discuss these issues. However, he noted that the work of these disciplines still tends to be separated. As much as this Symposium wanted to showcase the "neat" convergence of science and history, most presentations over these two days were either science-focused or history-focused. So, while this event was a good first step toward collaboration between historians and scientists, it's clear there's still work to be done to break down barriers of tradition that tend to keep individual disciplines siloed and working independently from one another.

[22] To learn more about Citizen Science, GLOBE, and the GLOBE Observer App, see **Globe Observer: Citizen Science in Support of Earth System Science**, in the November–December 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 6**, pp. 15–21].

Kelsey Herndon said that she had not had a history class since high school. She thought she would hear "cool stories of the past" at this Symposium and perhaps learn something from them, but it turned out to be a chance to reflect on how NASA (in her case, SERVIR) thinks about what it does and what is the larger historical context of the agency's achievements: *How has the past impacted who we are and what we do today—and who we can become and what we can do in the future?* Herndon and the other panelists also agreed that a forum like this helps us all to step out of our respective comfort zones and begin important conversations that hopefully lead to more interactions in the future.

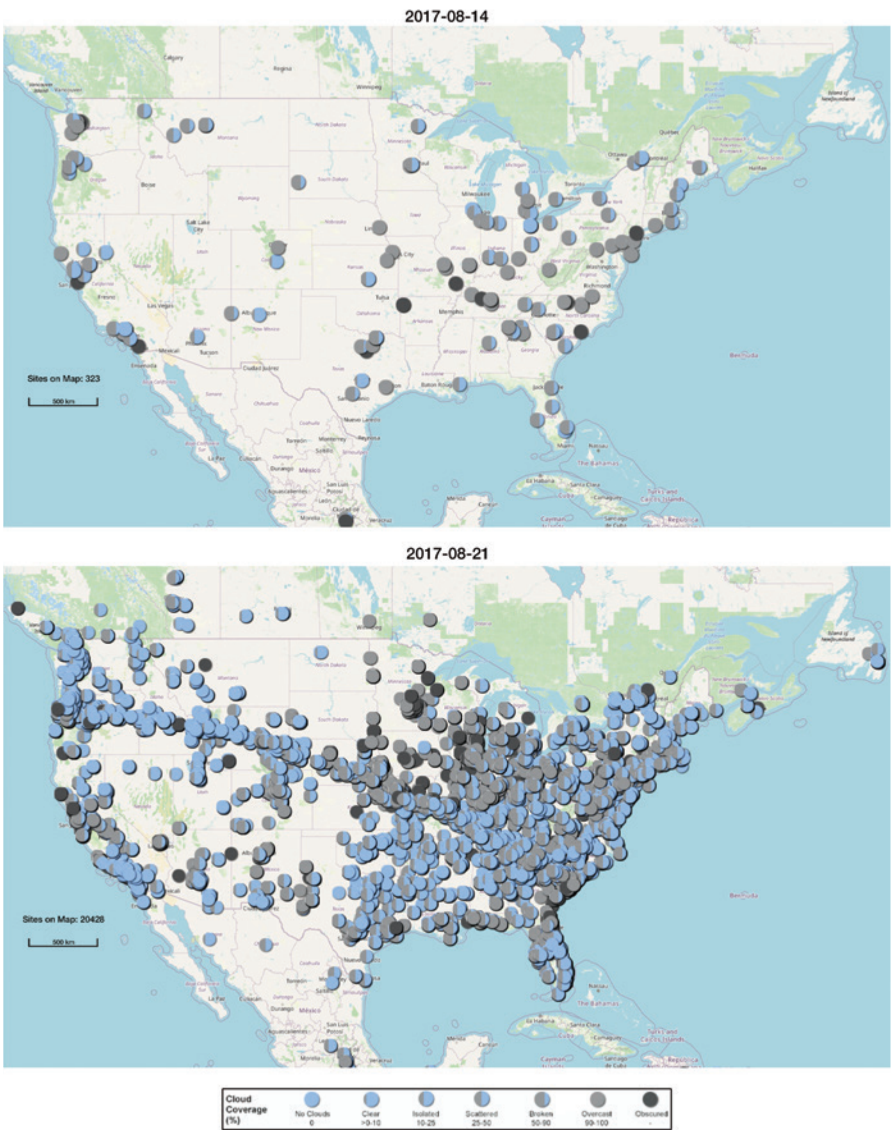

Figure 3. Shown are GLOBE Cloud observations from August 14, 2017 [*top*] and August 21, 2017 [*bottom*]—the date of the 2017 Great American Solar Eclipse. On the day of the eclipse, over 19,000 observations were submitted with more than 60,000 cloud photos. This dramatic increase in observations was enabled by the GLOBE Observer App's low barrier to entry. The path of totality can clearly be seen on the bottom map thanks to the engagement of numerous new observers. **Figure credit:** GLOBE Program

Dagomar Degroot added that historians of science tend to challenge the dominant narrative (noting that he heard this in several Symposium presentations) while scientists tend to reinforce the dominant narrative. Thus, the two groups often "talk past each other." Scientists are frequently the subjects of the historian. It's hard to find a middle ground at these conferences—but he thought that this Symposium did a good job at presenting a balance between historical and scientific perspectives.

Joshua Howe admitted that he's never been an advocate of being *interdisciplinary* purely for the sake of interdisciplinarity, i.e., while learning how different disciplines approach subject matter is good, being interdisciplinary is not an *end* in itself. Rather, it is a *means* to an end—that end being figuring out to work together to solve the big problems that our society faces. Simply put, there is synergy when traditionally separate disciplines come together and work toward a common goal. One need look no further than the field of Earth system science—and the coincident development of NASA's EOS—for a success story in interdisciplinary collaboration.

Bob Murphy agreed that this gathering was a good first step in bringing two seemingly disparate disciplines together. Hearing the specific story of Frank Press in **Ron Doel**'s presentation (in Session 3B) helped him put into perspective and fill in details of NASA's history that he had always been curious about. He also was reminded how much influence a single personality could have on large outcomes. Earlier he had cited Shelby Tilford as another of those powerful personalities in Earth Science history. Murphy noted that **Compton Tucker** highlighted another such towering personality in Piers Sellers.

In closing, Symposium Planning Committee member **Brian Odom** answered an audience question from **Andrew Ross** (who presented in Session 1B) about why the NASA History Office held this meeting—and why GU students (who made up a large part of the Keynote Panel Conversation audience) should care about the NASA History Office. Odom said that chronicling the work of the agency is what the History Office does. The History Office has done this with different topics in the past (e.g., civil rights) and certainly environmental history is an important topic to consider—particularly given its social relevance in the present moment. However, they also think about the questions asked: e.g., *What does NASA need to know? What will help the agency do its work better?* He noted that it is a leadership question, but the *answers* impact the workforce. Odom concluded by saying that the History Office seeks to engage history at every level, and therefore the crowd that gathered to hear the Keynote Panel Conversation is precisely the crowd they want to engage.

Anecdotal reports from attendees and presenters both indicate that the effort was eminently worthwhile and opened their eyes and cognition to aspects of human activity that—on the face of it—might not seem connected. But the past drives the present, which drives the future. Such a position was abundantly clear at this Symposium. ■

Historians of science tend to challenge the dominant narrative ... while scientists tend to reinforce the dominant narrative. Thus the two groups often tend to 'talk past each other.' Scientists are frequently the subject of the historian. It's hard to find a middle ground at these conferences—but this Symposium did a good job presenting balance between historical and scientific perspectives.
—Dagomar Degroot

Acknowledgments

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South/Southeast Asia Meeting on Air Pollution in Asia—Inventories, Monitoring and Mitigation

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Introduction

The 2023 **NASA Land Cover and Land Use Change** (LCLUC) program's **South/Southeast Asia Research Initiative** (SARI) thematic meeting was held February 1–3, 2023 in Hanoi, Vietnam—see **Photo 1** *below*. The Vietnam National University of Engineering and Technology (VNU-ET), the Vietnam National Space Center (VNSC), and the Vietnam Academy of Science and Technology (VAST) served as local meeting hosts. The meeting had 90 participants from several South/ Southeast Asian countries and the U.S. It was organized into eight different sessions over three days. The content included invited presentations, reports from the SARI Principal Investigators (PIs), and reports from regional scientists.

The tagline for the meeting was *Air Pollution in Asia—Inventories, Monitoring and Mitigation*. Meeting participants included SARI researchers as well as representatives of several other international programs, e.g., the **Global Observations of Forest and Land Use Dynamics** (GOFC-GOLD), **South/Southeast Asia Regional Information Networks**, researchers from Japan's **National Institute of Environmental Studies** (NIES), Regional and Space Agencies—including the **Association of Southeast Asian Nations** (ASEAN) intentionally gathering such a diverse group of participants allowed the meeting to achieve its objectives which were to:

- review greenhouse gas (GHG) and short-lived climate pollutant (SLCP) emission estimates and methodologies from different sources, including biomass burning in the Asian region;
- understand the impact of GHGs and aerosols on local climate, including health effects;
- explore the potential of satellite remote-sensing datasets for quantifying pollutants, aerosols, and pollution episodes;
- review modeling approaches for characterizing emissions; and
- strengthen regional information exchange and training activities through effective collaborations.

Photo 1. Participants at the NASA LCLUC SARI International Meeting on Air Pollution in Asia: Inventories, Monitoring and Mitigation, held February 1–3, 2023 in Hanoi, Vietnam. **Photo credit:** VNU-ET staff

Photo 2. Picture of participants at the Remote Sensing Fundamentals training workshop at RUA, February 8–10, 2023. The training is described on page 36 of this article. **Photo credit:** RUA, Cambodia Staff

Following the meeting, the Royal University of Agriculture (RUA) in Phnom Penh, Cambodia hosted a three-day training on Remote Sensing Fundamentals for early career scientists. Several who attended the LCLUC SARI meeting also participated in the training session—see **Photo 2** *above*.

The remainder of this article provides a detailed overview of the LCLUC SARI meeting and the training session—see *Training in Remote Sensing Fundamentals for Early-Career Researchers* on page 36. The LCLUC website contains the **full meeting agenda**, which includes links to many of the presentations described in the summary that follows.

DAY ONE

Session I: Inaugural Welcome Session

Local hosts, **Nguyen Hoai Son** [VNU-ET] and **Vu Anh Tuan** [VNSC], welcomed the participants and stressed the importance of collaborative efforts among satellite remote sensing experts and countries to tackle air pollution in Vietnam and the South/Southeast Asian region. **Marc Knapper** [Department of State—*U.S. Ambassador to Vietnam*] highlighted the significance of U.S.–Vietnam scientific relations in addressing air pollution. **Chris Justice** [University of Maryland, College Park (UMD)], **Toshimasa Ohara** [Center for Environmental Science in Saitama (CESS), Japan], and **Krishna Vadrevu** [NASA's Marshall Space Flight Center (MSFC)] also emphasized combining different approaches to measure emissions, link air pollution to health, and promote research, training, and capacity-building for young researchers in pollution monitoring and management—see **Photo 3** *above*.

Photo 3. Participants at the first session of the LCLUC SARI international meeting in Hanoi, Vietnam. On the dais [*left to right*] **Krishna Vadrevu** [MSFC], **Toshimasa Ohara** [NIES], **Marc Knapper** [Department of State—*U.S. Ambassador to Vietnam*], **Chris Justice** [UMD], **Nguyen Hoai Son** [VNU-ET], and **Vu Tuan** [VNSC]. **Photo credit:** VNU-ET staff

Session II: Programmatic Presentations

Chris Justice chaired this session.

Justice, Garik Gutman [NASA HQ] and **Krishna Vadrevu** reviewed the accomplishments of NASA's LCLUC program, including the Silver Jubilee celebration in 2022. The NASA LCLUC program is part of NASA's Earth Science Carbon Cycle and Ecosystems research focus area. Over the past 25 years, the LCLUC has funded over 300 projects involving more than 800 researchers—leading to over 1000 publications. The program focuses on three important components: detection and monitoring; impacts and consequences; and drivers, modeling, and synthesis—with projects distributed fairly evenly among the three components and integrating biophysical, socioeconomic, and remote sensing sciences. The annual LCLUC Science Team

(ST) meetings bring together researchers to discuss the latest LCLUC methods and data, present their findings, build collaborations, and provide program feedback. *The Earth Observer* has highlighted the origins and past updates of the LCLUC program.[1]

The next three presentations give updates on LCLUC in Vietnam, Thailand, and the Philippines.

Vu Anh Tuan presented VNSC's activities that are categorized into applications, engineering, and science and education. Vietnam's "Strategy of Space Science and Technology Development and Application to 2030" prioritizes national Earth observation capabilities and satellite development. VNSC has launched a series of small satellite missions: PicoDragon [1 kg (~2.2 lb)], 2013; MicroDragon [50 kg (~110 lb)], 2013–2018; and NanoDragon [4–6 kg (~8.8–13.2 lb)], 2017–2020. The upcoming LOTUSat-1 satellite [570 kg (~1257 lb)], which is a collaborative effort between VNSC and Japan's Nippon Electric Company (NEC) Corporation, features an X-Band Synthetic Aperture Radar (SAR) for diverse applications. Tuan emphasized satellite remote sensing's role in disaster monitoring, agriculture, environmental monitoring, urban planning, national security, and emergency response. VNSC provides analysis-ready data, including a **comprehensive Data Cube** from 1986 to the present, that aids national forest and rice monitoring. Capacity building and outreach are also core aspects of VNSC's mission.

Kandasri Limpakom [Geo-Informatics and Space Technology Development Agency (GISTDA), Thailand] provided updates on recent agency initiatives. GISTDA launched the Thailand Earth Observation satellite (THEOS) in 2008. It features THEOS Optical Payload. [TOP]-Panchromatic (TOP-PAN) with a 2-m (~6.6-ft) ground sample distance (GSD) and 22-km (~14-mi) swath. In addition, the THEOS Optical Payload-Multispectral (TOP-MS) operates across four bands with a 15-m (~49-ft) GSD and 90-km (~56-mi) swath. THEOS images are useful for land-use planning and disaster management. THEOS-2, which launched on October 9, 2023,[2] offers even higher resolution [2-m Red-Green-Blue, (RGB) visible and near infrared (NIR), 0.5 m (~1.6 ft) panchromatic] with a four-day revisit cycle. GISTDA is also working on THEOS-2A, a small satellites mission that will have 1.07-m (~3.5-ft) resolution, a two-day revisit interval, and a three-year design lifespan. GISTDA is collaborating with Swedish Space Corporation (SSC) to establish a comprehensive ground segment that focuses on applications addressing Thailand's environmental challenges, e.g., air pollution, deforestation, and climate change. GISTDA's applications extend to providing concentrations of particulate matter (PM) with diameters 2.5 μm or less ($PM_{2.5}$) using multisensory integration for the entire country. This application also contributes to **Airborne and Satellite Investigation of Asian Air Quality** (ASIA-AQ), a campaign supporting ground-based instruments.

Gay Jane Perez [Philippines Space Agency (philSA)] discussed air quality monitoring efforts in the Philippines. Established in 2019, the air quality theme is within the Hazard Management and Climate Studies section of philSA. In the Philippines, vehicle emissions are the main source of urban air pollution—surging from two million tonnes in 2002 to 20 million tonnes in 2018. Aerosol optical depth (AOD) varies based on long-range pollution, while total particulate matter (TPM) varies nationwide, reaching 760,000 tons annually in the National Capital Region. The **Pan-Asia Partnership for Geospatial Air Pollution Information Project and the Pandora Asia Network (PAPGAPI–PAN) Philippines** project, with collaboration from philSA, South Korea, and the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), integrates ground and satellite data for pollution monitoring, using the South Korean **Geostationary Environment Monitoring Spectrometer** (GEMS) instrument data products. Future plans are to use GEMS data to establish an operational air quality system and emphasize capacity building and training during the data-to-policy transition.

Krishna Vadrevu provided an update on SARI activities. The organization is serving as a facilitator and catalyst for LCLUC research in South/Southeast Asia. It enhances regional and national projects through collaborative efforts among researchers from various institutions. The initiative aims to improve LCLUC mapping, monitoring, and impacts assessment through shared methodologies and data. SARI has led to numerous activities, including meetings, training, publications, collaborations, and field visits. Altogether, there have been 27 **projects** funded by the LCLUC program, leading to hundreds of published papers and collaborations with space agencies, organizations, universities, and decision makers around the world. SARI also conducts training events for young researchers (e.g., the one described in the sidebar on page 36) and ongoing synthesis projects to assess recent progress in the discipline.

Nguyen Thi Nhat Thanh [VNU-ET] presented on **Improving Air Pollution Monitoring and Management in Vietnam with Satellite $PM_{2.5}$ Observations**, a project funded by the U.S. Agency for International Development's (USAID) Long-Term Assistance and Services for Research (LASER) Partners for University-Led Solutions Engine (PULSE) program. Air pollution—especially $PM_{2.5}$—is a serious problem

[1] See **NASA's Land-Cover and Land-Use Change Science Team Celebrates 25 Years** in the March–April 2023 issue of *The Earth Observer* [**Volume 35**, **Issue 2**, pp. 12–24].
[2] **UPDATE:** **THEOS-2 successfully launched** on October 9, 2023.

in cities like Hanoi and Ho Chi Minh City in Vietnam. Limited ground stations hinder national air quality assessments. In fact, satellite data provide the only source of data for much of the country. The project provides $PM_{2.5}$ data, creates communication products, and collaborates other institutions—e.g., Phennika University, Vietnam's Environmental Pollution Control Department and Ministry of Natural Resources and Environment, and the University of Maryland. Key products include 2019–2021 daily $PM_{2.5}$ maps, a health impact report, a real-time WebGIS platform, and educational videos. The project used a Mixed Effect Model with various data sources to create a national-scale $PM_{2.5}$ dataset.

Session III - GHG and Pollutant Emission Inventories including Decision Support Systems

Toshimasa Ohara and **Nguyen Thi Nhat Thanh** were cochairs for the session.

Matsunaga Tsuneo [NIES] discussed the Japanese **Greenhouse Gases Observing Satellite** (GOSAT) series, [which includes the GOSAT, GOSAT-2, and **Greenhouse Gases Observing Satellite and Water Cycle** (GOSAT-GW) missions]. GOSAT, launched in 2009, employs a Fourier Transform Spectrometer (FTS) to measure carbon dioxide (CO_2) and methane (CH_4) levels. GOSAT-2, launched in 2018, also uses FTS to measure CO_2, CH_4, as well as carbon monoxide (CO). Tsuneo showed results from a recent analysis of GOSAT data from 2011–2022 that indicates an 8 ppb/yr increase in whole-atmosphere CH_4. He also showed the **GOSAT-2 product archives**, which contains information about GOSAT-2 products and services.

GOSAT-GW, now set for launch in Japan's Fiscal Year 2024 (FY24), will use the Total Anthropogenic and Natural emissions mapping SpectrOmeter-3 (TANSO-3) to detect CO_2, CH_4, and nitrogen dioxide (NO_2). (It also has the Advanced Microwave Scanning Radiometer–3, or AMSR-3, onboard.) Collaborative initiatives between NIES, the Ministry of the Environment (MOE), and the Japan Aerospace Exploration Agency (JAXA) are in progress. NIES plays a pivotal role in data generation, validation, distribution, and archiving that is supported by science teams of domestic experts. International partnerships with foreign space agencies enhance project scope and impact, e.g., the **GOSAT Series Research Announcement** invited global researchers to contribute and benefit from the joint efforts.

Toshimasa Ohara presented "Long-Term Trends of Anthropogenic Emissions in East/Southeast Asia," a heavily polluted region that contributes nearly half of global emissions. Ohara's team developed the **Regional Emission Inventory in Asia** (REAS) spanning 1950–2015—with an ongoing update to 2018—emphasizing South and Southeast Asia. Data include various species at 0.1° x 0.1° resolution and monthly frequency. The data show that global and East Asian emissions of oxides of nitrogen (NO_x) have decreased since 2010, contrasting India and Southeast Asia's rising trends. In Southeast Asia, NO_x and sulfur dioxide (SO_2) emissions increased from 1990–2018, while black carbon (BC) emissions peaked in 2007. Biomass burning impacts aerosol optical depth and pollution in some Southeast Asian nations. China's annual NO_2 column emissions align with modeled emissions over time.

The topics covered in the other technical presentations in the session are summarized below. In South Asia, particularly in India, understanding air pollution sources through emission inventories is crucial. One study focused on a new emissions inventory covering 17 sectors, utilizing a 0.4 km x 0.4 km (~0.25 mi x 0.25 mi) grid resolution. Results reveal that aging vehicles (>15 years old) contribute around 35–40% to road-transport emissions, while two-wheelers and commercial cars contribute 35-45% to windblown road dust. Municipal solid waste burning emerges as a significant pollution source in megacities. Dhaka, Bangladesh—a highly polluted city—faces challenges from both distant pollutant transport and local emissions, with industries, traffic, and biomass burning being the main contributors. These trends are more pronounced during the dry season.

In Hanoi, Vietnam, air pollution stems from PM_{10}, $PM_{2.5}$, and other gases (CO, SO_2, NO_2, CH_4). Urban and industrial activities are the main PM sources, while thermal power plants contribute 3.3%. The Ministry of Natural Resources and Environment's National Remote Sensing Department integrates diverse data from the European Space Agency's (ESA) Copernicus **Sentinel-5P** and the joint U.S. Geological Survey–NASA **Landsat** satellites, ground stations, and unpiloted aerial vehicle (UAV) measurements. The **Horiba PX-375 continuous particulate monitor** offers $PM_{2.5}$ ground-based measurements in 30 mins. This approach utilizes big data and remote sensing for efficient air pollution monitoring in waste treatment zones, industrial parks, and craft villages.

DAY TWO

Session IV: Land Use and Emissions

Krishna Vadrevu and **Edgar Vallar** [De La Salle University, Philippines] cochaired this session.

Son Nghiem [NASA/Jet Propulsion Laboratory (JPL)] presented on the effects of three-dimensional (3D) urbanization patterns and topography on air pollution processes in Asia, introducing an innovative approach called the Dense Sampling Method (DSM) applied data from NASA's Quick Scatterometer (QuikSCAT) to achieve reliable urban observations at ~1 km (~0.6 mi) resolution. Researchers used this method, along with digital surface model (DSM)-based change indices, to infer 3D-building volume in several U.S. cities. The data were validated with airborne lidar data. The researchers used the same approach in Beijing, China from 2000–2009—see **Figure 1** *below*—to link urbanization to NO_2 pollution. These results were then input into the urban-climate-nested Gas-Aerosol-Transport-Radiation–General-Circulation-Mesoscale-and-Ocean Model (GATOR-GCMOM) to assess the impact of urbanization on air pollution. The results show that increased urbanization leads to rising urban heat, drier soil conditions, increased air stagnation, worsening smog, heightened ozone (O_3) pollution, and greater upward pollutant mixing. Nghiem also showed results from a similar study conducted in New Delhi, India, from 2000–2009 that used DSM urban change input to showcase *ring effects* marked by high turbulent kinetic energy, low wind, increased mixing, stagnant air, and exacerbated air pollution.

Sumeet Saxena [East West Center] presented peri-urbanization, land-use, and air quality patterns in Vietnam. The study revealed highest $PM_{2.5}$ median and O_3 median concentrations in *peri-urban* areas, which are transitioning from rural to urban, both nationally and provincially. For example, median $PM_{2.5}$ concentrations are highest in peri-urban areas nationwide and in most provinces, except for Bac Ninh, Binh Duong, and Dong Nai. Similarly, median ozone concentrations are highest in peri-urban areas nationwide and in most provinces, except for Hanoi, Binh Duong, Binh Phuoc, and Dong Nai. Pollution sources include construction, industry, power generation, brick kilns, handicraft villages, household cookstoves, open crop burning, and wildfires The data reveal that the traditional rural–urban divide is no longer applicable. These transitional zones face compounded environmental risks and present a complex scenario with governance challenges arising from misclassification of areas.

One presentation in this session highlighted the use of lichens to assess nitrogen risk in Himalayan forests and the Indo-Ganges region in India. Lichen interact with their surroundings, absorbing water and nutrients from the air. Different lichen species have varying tolerance levels to nitrogen pollution, collectively indicating excessive nitrogen levels. Elevated nitrogen can lead to lichen mortality. Himalayan ecosystem research reveals lower nitrogen content in forest lichens compared to trees outside the forest—implying pollution's impact on these ecosystems.

Other presentations focused on LCLUC and emissions in Vietnam. The Middle Mekong Delta has industrial zone growth, peri-urban expansion, and shifts from rice to specialized fruit and flower cultivation. The Lower Mekong Delta is transitioning from rice crops to vegetable crops, with notable sod cultivation along rivers for housing development. Coastal lands are transforming into aquaculture, primarily shrimp farming, which has led to significant mangrove loss. The Mekong River Delta is shifting from rice cultivation towards multiple crops, accompanied by rice field consolidation, increased aquaculture, and crop diversity. In the Northern Uplands there is a shift from *swidden/*

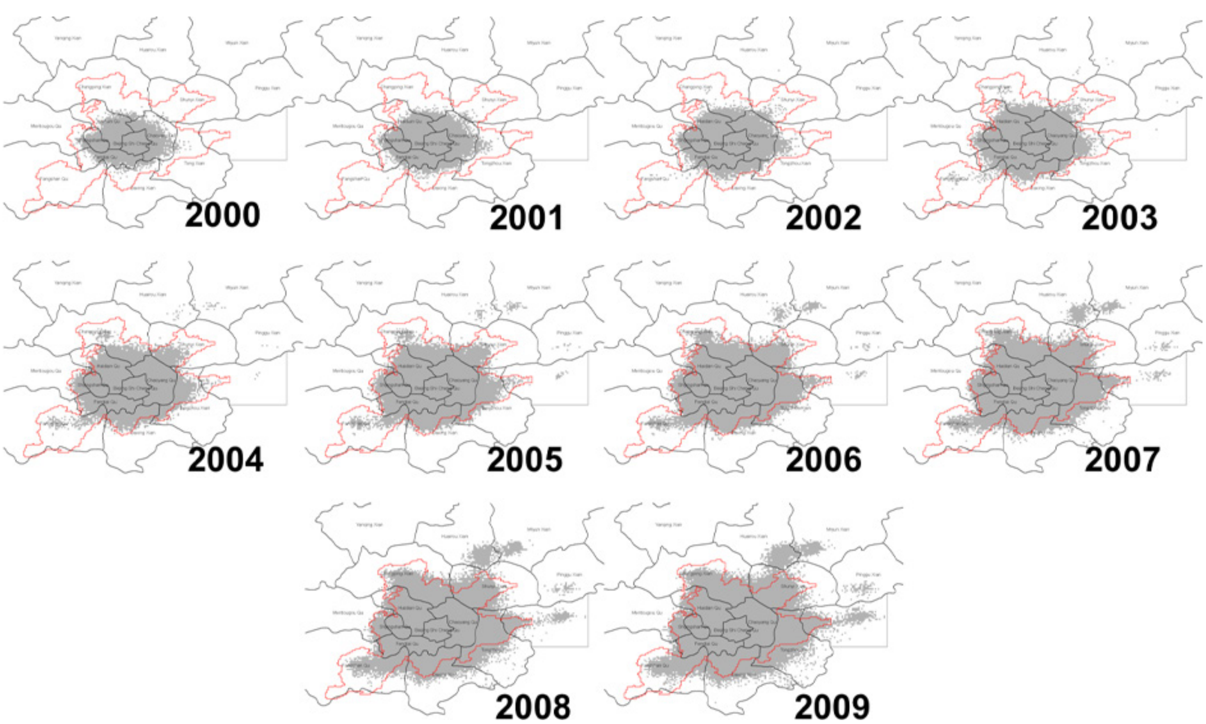

Figure 1. Urban extent in Beijing, China from 2000–2009, derived using data from NASA's Quick Scatterometer (QuikSCAT). **Figure credit:** Sun Nghiem/JPL

fallow[3] into permanent tree crops (e.g., rubber, coffee, and fruit) or annual crops (e.g., maize, cassava, and legumes). The Central Highlands are also transitioning from swidden/fallow to tree crops (e.g., coffee, rubber, pepper, and cashew) with fruit tree expansion. These shifts in crops could lead to reduced biodiversity, escalated fertilizer and pesticide use, and soil erosion. These agricultural shifts could also impact water pollution. Mangrove replacement with shrimp ponds impacts resilience, biodiversity, and ecosystem processes. Overall, these shifts highlight the intricate link between land use and environmental consequences in Vietnam.

The Ho Chi Minh City Space Technology Application Center in Vietnam is actively involved in rice mapping and monitoring projects, which are crucial for estimating CH_4 emissions. The Center employs SAR and optical datasets to create rice maps for the Mekong area, along with monthly phenology/growth stage and crop production/yield estimates—e.g., see **Figure 2** *right*. These outputs align with regional initiatives and are shared with the Ministry of Agriculture and Rural Development's Department of Crop Production and the Center for Informatics and Statistics. VNSC initiated the **Space Applications for Environment (SAFE) Rice Monitoring project** in collaboration with the Indian Space Research Organisation (ISRO), GISTDA, and JAXA. The project develops CH_4 emission estimation methodologies for rice paddies, emphasizing data sharing, capacity building, and cross-organizational collaboration.

Another presentation highlighted the resuspension of road dust as a notable source of $PM_{2.5}$, PM_{10}, and total suspended particles (TSP)] in Hanoi, Vietnam. Improving the Emission Inventory (EI) of road dust helps align monitored and simulated $PM_{2.5}$ levels and composition, consequently enhancing air quality. Overcoming challenges in improving the accuracy of soil/road dust EI requires monitoring data to quantify activity and emission factors on different road types, ultimately refining the EI formula for local conditions.

Session V: Air Quality and Health Including COVID Impacts

Masahiro Kawasaki [Kyoto University, Japan] and **Steve Leisz** [Colorado State University] cochaired the session.

Rajasekhar Bala [National University of Singapore] presented a study that compared commuters' personal exposure (PE) to $PM_{2.5}$ and BC in Singapore and Danang, Vietnam. Both cities are located along the coast and share similar tropical climates with consistent ambient $PM_{2.5}$ mass concentrations ranging from 14.0 to 25.0 µg/m and no notable seasonal patterns. However, transportation preferences vary significantly. In Singapore, 53% use public transport, 29% use private vehicles (cars and taxis), 4% carpool, and 14% choose active mobility (walking and cycling). In contrast, 98% of Danang commuters use motorcycles, with the remaining 2% utilizing public or private transport. Real-time PE measurement revealed that over 60% of the inhaled dose of $PM_{2.5}$ during a road trip between the two cities occurred within the airport concourse and transit micro-environments, i.e., on an apron bus. Comparing the two cities, the PE, $PM_{2.5}$, and BC from transport micro-environments was an order of magnitude higher in Danang than Singapore. The researchers attributed elevated particle levels in Singapore to heavy-duty diesel vehicles whereas motorcycles were the primary source in Danang. Thus, motorized transport affects urban commuters' life expectancy compared to active mobility (i.e., cycling).

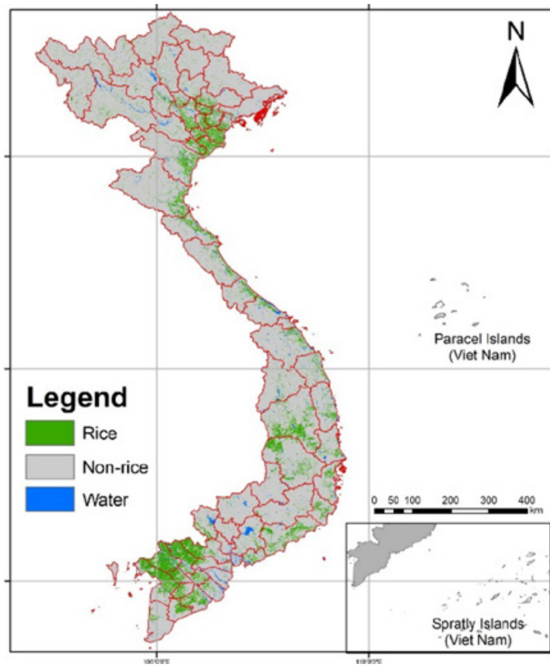

Figure 2. Rice map of Vietnam for May–October 2018 (which is the rainy season in Vietnam) produced using Sentinel-1 data. **Figure credit: Lam Dao Nguyen**/Ho Chi Minh City, Space Technology Application Center, Vietnam National Space Center.

Another study examined the effects of short-term ambient air pollution on hospitalizations among children aged 0–17 for pneumonia, bronchitis, and asthma in Hanoi, Vietnam. All air pollutants—except O_3 and SO_2—were associated with increased pneumonia hospitalizations. NO_2 was associated with a 6.1% increase. These trends held when considering two pollutants together. Bronchitis and asthma hospitalizations

[3] The swidden/fallow cycle, or slash-and-burn agriculture, is a traditional farming method used by many indigenous and traditional communities, especially in tropical regions, that entails clearing and burning of forests or natural vegetation, to create nutrient-rich ash. This land is then used for crop cultivation for a limited time, usually a few seasons. When soil fertility declines, the area is left fallow, allowing natural regeneration.

were positively linked to all pollutants except CO—especially in infants compared to children aged 1–5. Additionally, higher PM concentrations correlated with more cardiovascular-related hospital admissions for those older than 15.

Another experiment, conducted in Bien Hoa City, southern Vietnam, assessed heavy metal concentrations in $PM_{2.5}$, classifying them into high, moderate, and low concentration categories. Certain metals exhibited enrichment factors suggesting significant potential cancer risk. Emissions from other Southeast Asian countries also contributed to pollution in Bien Hoa City through atmospheric transportation.

DAY THREE

Session VI: Aerosol Pollution

Maria Cecilia Galvez [De La Salle University] and **Hoang Anh Le** [Hanoi Vietnam University of Science, VNU, Vietnam] cochaired this session.

Eric Vermote [GSFC] presented the keynote **generic method for retrieval of aerosols over land**. Using satellite data to create a continuous land climate data record requires calibration, atmospheric corrections, and bidirectional reflectance corrections. The Surface Reflectance algorithm (LaSRC) was developed to validate and automate quality assurance processes. Surface reflectance retrievals from **Landsat 8**/Operational Land Imager (OLI) and Sentinel 2/MultiSpectral Instrument (MSI) rely heavily on LaSRC developed for Collection 6 (C6) of the **Moderate Resolution Imaging Spectroradiometer** (MODIS) data.[4] The accuracy of the data can be guaranteed because of its link to validated radiative transfer code, facilitating error assessment. Additionally, *bidirectional reflectance distribution function* (BRDF)[5] correction can be incorporated, allowing for comparisons with other sensors (e.g., **Visible Infrared Imaging Radiometer Suite** (VIIRS),[6] **Advanced Very High Resolution Radiometer** (AVHRR),[7] **Landsat**, **Sentinel 2**, and **Sentinel 3**).

One science presentation in this session highlighted the operational NASA **Aerosol Robotic Network** (AERONET) station active since 2018, at Dibrugarh University, Assam (northeast India's Upper Brahmaputra Basin). Anthropogenic sources like biomass burning, oil refineries, tea industry (from burning of crop residue), brick kilns, and emissions contribute to higher aerosol concentration in this area. Air mass transport and aerosol mixing vary due to the Indo-Gangetic Plain (IGP) outflow. Notably, MODIS-derived AOD and AERONET AOD values are well correlated ($R^2 = 0.68$). In 2020, a shift occurred from scattering aerosols to absorbing aerosols, which led to increased atmospheric heating. Results indicate that the diurnal aerosol size distribution changes depending on meteorological conditions.

Another presentation highlighted how distinct burning and non-burning periods align with dry and wet monsoon seasons in Southeast Asia. The **Seven SouthEast Asian Studies** (7-SEAS), which ran from 2013–2015, studied the interaction between aerosols produced by biomass burning in the stratocumulus environment. Data collected during 7-SEAS determined that BC accounts for about 6% of the total $PM_{2.5}$ concentrations and 12% of the AOD—making up 75% of the regional atmospheric forcing by composite aerosols. Biomass burning in northern Southeast Asia primarily produces organic matter (OM). In Chiang Mai, daily BC concentrations primarily arise from biomass burning, which occasionally accounts for up to 92% of the total, with an average contribution of 59% of daily BC levels. Higher elemental carbon (EC) and dust levels suggest a combined source from traffic and biomass burning.

There was also a report on the significance of haze impacting visibility—particularly in Hanoi, Vietnam. Haze episodes are determined by PM levels, meeting World Meteorological Organization (WMO) criteria of visibility between 1–5 km (~0.6–3 mi) and specific humidity benchmarks. During a dry winter, Hanoi typically witnesses 4–7 *haze periods*—where $PM_{2.5}$ surpasses 50 $\mu g/m_3$, visibility is less than 5 km (~3 mi)—and relative humidity is below 90% for 1–4 days. Haze, particularly in Lower Southeast Asia during summer, is exacerbated by long-range transport from Southeast Asian biomass burning. Haze periods exhibit higher levels of Secondary Inorganic Aerosols (SIA). Approximately 50% of $PM_{2.5}$ variations, whether in haze or non-haze conditions, can be attributed changes in relative humidity.

Vertical profile measurements of air quality are vital for understanding pollution. A study conducted in Shah Alam, Malaysia, used UAVs flying at ~120 m (~394 ft) to examine $PM_{2.5}$ and PM_{10}. Pollutants accumulate higher in the atmosphere during the dry season, where

[4] MODIS instruments fly on NASA's Terra and Aqua platforms.

[5] The *bidirectional reflectance distribution function* (BRDF) defines how light is reflected at an opaque surface. In remote sensing it's used for correction of view and illumination angle effects (e.g., in image standardization and mosaicking), for deriving albedo, for land cover classification, for cloud detection, and for atmospheric correction.

[6] VIIRS instruments fly on the Suomi National Polar-orbiting Platform (Suomi NPP) and on the National Oceanic and Atmospheric Administration's (NOAA)-20 and -21 platforms.

[7] AVHRR instruments have flown on various NOAA, NASA, and international platforms since 1979. Current operational AVHRR instruments fly on NOAA-15, -18, and -19 platforms and on the European Metop -B and -C platforms.

mixing is limited. However, cleaner air at altitude does not prevent transport at lower levels. Conversely, humid conditions reduce PM_{10}, leading to a negative PM–humidity correlation.

Researchers studied Thailand's average $PM_{2.5}$ levels from 2002–2021. Analysis of January and February data for this two-decade period revealed high $PM_{2.5}$ concentrations in the Central Region, with rising concentrations noted in the east and border areas. Data from the same time period for March and April showed elevated levels in the north, with a growing trend in the northeast along the border.

Session VII: Biomass Burning Emissions

Nguyen Thi Kim Oanh [Asian Institute of Technology (AIT), Thailand] and **Lam Dao Nguyen** [VNSC, VAST] served as session cochairs.

The keynote speaker, **Chris Justice**, discussed pre-fire, fire, and post-fire MODIS data from 2000 to the present. He explained that the Terra and Aqua missions are approaching their end of life and are experiencing orbital drift affecting altitude and timing. Based on recent guidance provided by NASA HQ, Terra and Aqua are expected to continue providing MODIS Land science products for at least three more years—through U.S. FY26. After that, the team is directed to initiate mission termination (Phase F) in FY27. The drifting orbits will provide valuable diurnal information, and the MODIS Science team is requested to take this into consideration as they plan their algorithm maintenance activities The MODIS–VIIRS Science Team is also pursuing other options for morning data continuity from international satellites, e.g., Sentinel 3 and European Organisation for the Exploitation of Meteorological Satellites' (EUMETSAT) **MetOp-Second Generation** (SG) mission's **METimage** instrument.[8]

Another presentation during this session focused the Global Observations of Forest Cover and Land-use Dynamics" and then put the acronym "(GOFC-GOLD) Program and the planned Canadian **WildFireSat** satellite. The discussion examined the impact of COVID on vegetation fires in 2020 COVID year compared to the pre-pandemic period (2012–2019) in South/Southeast Asia (S/SEA). During 2020, fire counts in S/SEA declined, with exceptions for Afghanistan, Sri Lanka, Cambodia, and Myanmar. Most S/SEA countries also saw a decrease in burnt area or fewer fires during the COVID year. In addition, the PM emissions associated with fires declined in both South Asia and Southeast Asian countries from 2012–2019.

In another presentation there was a discussion about how Laos, which has forests covering 62% of the land, faces significant fire occurrences, particularly during the peak season in March. Forests account for the highest annual burnt areas in Laos, followed by grasslands and croplands. An analysis of data from 2001–2020 revealed an increase in forest fires—primarily in Xayabouly, Oudomxay, Louang Prabang, and Louang Namtha provinces in northern Laos—see **Figure 3** *below*. Limited ground-based air pollution measurements are available in Laos; however, MODIS satellite data reveals elevated $PM_{2.5}$ concentrations in the northern provinces. The National University of Laos collaborates with King's College, London, on *in situ* air pollution measurements linked to biomass burning.

[8] To learn more about the topics discussed in this paragraph, 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].

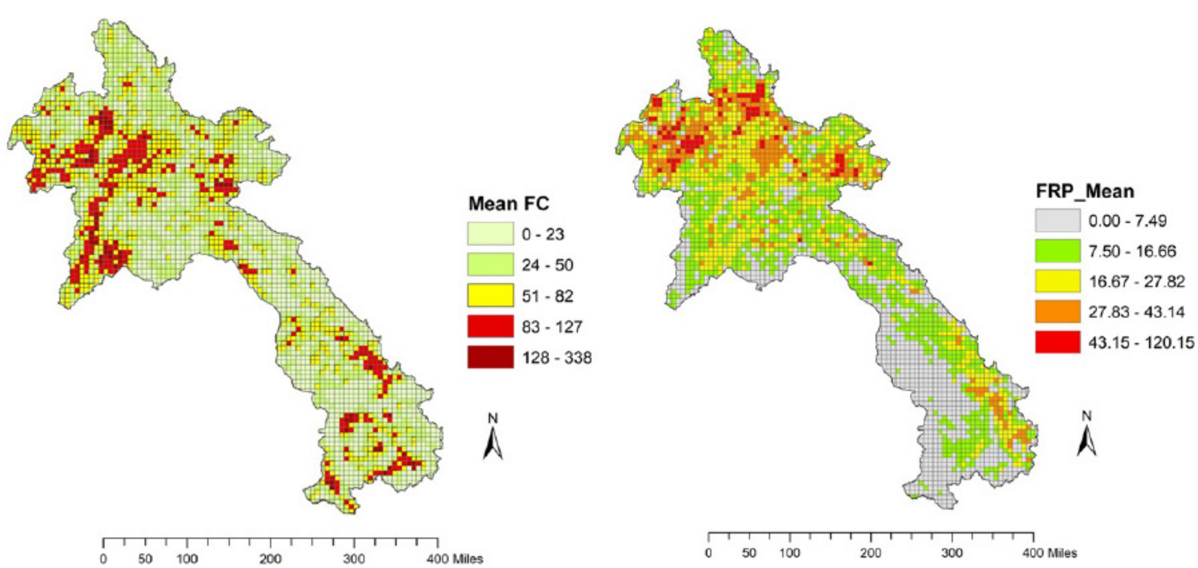

Figure 3. VIIRS-detected fire counts (FC) and fire radiative power (FRP) in megawatts, gridded at 1-km (~0.6-mi) intervals in Laos. Note that the majority of fires with high intensity (FRP) are concentrated the northern provinces of Laos. **Figure credit:** Krishna Vadrevu/MSFC

Training in Remote Sensing Fundamentals for Early-Career Researchers

From February 8–10, 2023, the RUA in Phnom Penh, Cambodia, hosted a training session to teach fundamental remote sensing skills to new scientists. Altogether, 65 participants, representing a variety of organizations in Cambodia, participated in the training—See photographs *below*.

The first day of the training began with **Krishna Vadrevu**, **Chris Justice**, **Kim Soben** [RUA], and **Thav Sopheak** [RUA] welcoming the participants. **Thuy Le Toan** [Centre d'Études Spatiales de la Biosphère (CESBIO), France] introduced general concepts of Synthetic Aperture Radar (SAR), followed by specific sessions that focused on using SAR data for forest monitoring and biomass. **Stephane Mermoz** [Global Earth Observation (GlobEO), France] and **Alexandre Bouvet** [CESBIO] presented practical case studies on using SAR for forestry applications.

The second day included practical case studies for using SAR data. **Son Nghiem** facilitated sessions on satellite active and passive microwave theory and applications to remote sensing of inland environments.

On the final day, **Wataru Takeuchi** [University of Tokyo, Japan] presented on land cover classification using Google Earth Engine and **Sridhar Venkataramana** [Virginia Tech] presented on soil and water assessment tools—including a demonstration. The training concluded with certificate distribution for the participants.

This training event also facilitated new collaborations, including learning opportunities for researchers in South/Southeast Asia.

[*Top left*] Participants engage with the training committee members [*left to right*]: **Thav Sopheak** [RUA], **Chris Justice** [UMD], **Krishna Vadrevu** [MSFC], **Alexandre Bouvet** [CESBIO, France], **Son Van Nghiem** [JPL], **Thuy Le Toan** [CESBIO], and **Kim Soben** [RUA]. [*Top right*] Trainer and host presenters include [*left to right*] **Wataru Takeuchi** [University of Tokyo], **Thav Sopheak** [RUA], **Krishna Vadrevu**, **Kim Soben**, and **Sridhar Venkatarama** [Virginia-Tech]. The two *bottom* pictures depict participants receiving their training certificates upon completion. **Photo credit:** RUA, Cambodia Staff

Another presentation examined the CO_2 emissions in smoke plumes from Indonesian peatland burning, which exceeded 415 ppm. $PM_{2.5}$ levels (800 µg/m^3) were estimated through a comparison of Japanese Himawari albedo data to AERONET AOD data (R^2 = 0.98). This relationship offers the potential of satellite data to derive PM concentrations from peatland fires in Indonesia.

Session VIII: Breakout Discussions

The final session focused on specific topics, including standardizing emission inventories, air quality and health, and air pollution, and decision support systems. The summaries of these sessions are provided below.

Standardized Emission Inventories

Hoang Anh Le, **Bich Thuy Le** [Hanoi University of Technology], and **Nguyen Thi Kim Oanh** facilitated this discussion, with **Saroj Sahu** [Utkal University, India] serving as note taker. The participants stressed the importance of creating standardized emission inventories for various sectors. They highlighted the significance of using quality activity data and regional technological emission factors (EFs) to ensure robust inventories. The group also emphasized the need to collaborate with research groups and governments to develop accepted emission products for mitigation. They identified challenges, including the need for training in emission inventory development and inverse modeling. The group highlighted the importance of SARI's assistance, including capacity-building workshops for increasing public awareness and seeking support from international research communities, like GEIA and TF-HTAP.

Air Quality and Health

Steve Leisz facilitated this discussion, with **Nhung Nguyen** [Hanoi University of Public Health, Vietnam] serving as note taker. The participants prioritized assessing and publishing data on a wide spatial scale, investigating the combined effects of different pollutants, examining broader impacts beyond human health, promoting collaboration and data sharing across locations, and fostering collaboration between environmental and health scientists. They noted that inadequate government funding, health study challenges (e.g., data privacy and ethical constraints), and limited capacity to employ research modeling tools all make this effort more challenging. The group concluded that emphasis should be placed on sharing international experience, developing the skills of students through various means (e.g., summer institutes), capacity building, and training in remote sensing, modeling, and effective communication. Participants also thought it was important to organize meetings and training sessions to encourage collaboration and skill enhancement. Additionally, they stressed the importance of online and virtual platforms for training and skill development.

Air Pollution and Decision Support Systems

Edgar Vallar and **Nguyen Thi Nhat Thanh** facilitated this discussion, which centered on translating research results to end-users and the role of different partners in this process. The participants prioritized actions to make data available, link governments, scientists, and science communication groups, connect air-quality research to health and economics, and develop translation products like a web system with a common language. They also suggest using the Air Quality Index (AQI) to present data and communicate health effects to the public. The group emphasized the importance of collaboration between scientists and science communication groups to disseminate information. They felt a major obstacle to effective communication was limited government funding for science translation. They also stressed the role of the private sector in technology development, public-private partnerships, and addressing sustainability challenges. Participants noted that international programs like SARI should continue meetings, workshops, training, data sharing, and science communication to foster collaboration and address air quality challenges in the region.

Conclusion

Overall, the SARI meeting on air pollution successfully achieved its objective of bringing together LCLUC and atmospheric researchers from various countries to further develop project partnerships and collaborations, address and improve ongoing issues related to air pollution in Asia, and gather community feedback regarding LCLUC SARI science. The training event in Cambodia was also highly productive and aided early career researchers in understanding the potential of remote sensing and geospatial technologies.

The meeting outputs are being compiled for publication in a special issue of the journal, *Environmental Pollution* entitled. **Greenhouse Gas Emissions and Air Pollution in Asia – Measurements, Mapping, and Monitoring**.

Looking ahead, the **next LCLUC/SARI-related training and meeting events** are scheduled to take place January 29–February 2, 2024 in Hanoi, Vietnam. Additionally, the **next LCLUC Science Team Meeting** will occur in April 2024. Members of the NASA LCLUC community are strongly encouraged to register early and attend. ■

Summary of the Final Activities of the 2018–2023 Landsat Science Team

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Introduction

The Landsat Program celebrated its semicentennial on Saturday, July 23, 2022, with events on Capitol Hill and a Senate resolution designating the day as "Landsat 50th Anniversary Day" or **Landsaturday**. The milestone anniversary, which honored five decades of continuous Earth observations from space via a long-running partnership between NASA and the U.S. Geological Survey (USGS), was also commemorated throughout the year at conferences and meetings.[1] Following this landmark celebration, this article presents a highlight of the accomplishments and recent activities of those who have supported the Landsat Program, including the 2018–2023 Landsat Science Team (LST)—see **Photo 1** *below*.

For decades LST has been home to agency scientists and engineers, application specialists, members of industry, university professors, and researchers, who have contributed their scientific and technical expertise to ensure the continued success of the Landsat Program. Members have been pivotal in developing novel research and sound-science applications. The high-quality data and robust calibration standards resulting from their work define Landsat as the multispectral reference standard for terrestrial land observations.

LST members provide the relevant input to address the growing and diverse needs of Landsat data users. Among a wide range of tasks, they are responsible for providing recommendations about the radiometric and geometric quality of data and performance of new remote sensing instruments; defining innovative strategies, algorithms, and science products; and advancing methods for multidecadal and large-area land and aquatic change assessments. The 2018–2023 LST focused on ensuring that data from Landsat 9 was integrated into the Landsat archive and that future Landsat science requirements (e.g., Landsat Next) reflected evolving user needs while maintaining observational continuity with past and current Landsat missions.[2] The 2018–2023 LST also maintained Landsat

[1] See, for example, **NASA Participates in Pecora 22 Symposium and Celebrates Landsat 50th Anniversary**, in the November–December 2022 issue of *The Earth Observer*. [**Volume 34**, **Issue 6**, pp.4–9].

[2] To learn more about Landsat 9 in the context of the broader history of Landsat, see **The Legacy Continues: Landsat 9 Moves Landsat Toward a Golden Milestone**, in the July–August 2021 issue of *The Earth Observer* [**Volume 33**, **Issue 4**, pp. 4–12]. This article references other articles in The Earth Observer that discuss Landsat history.

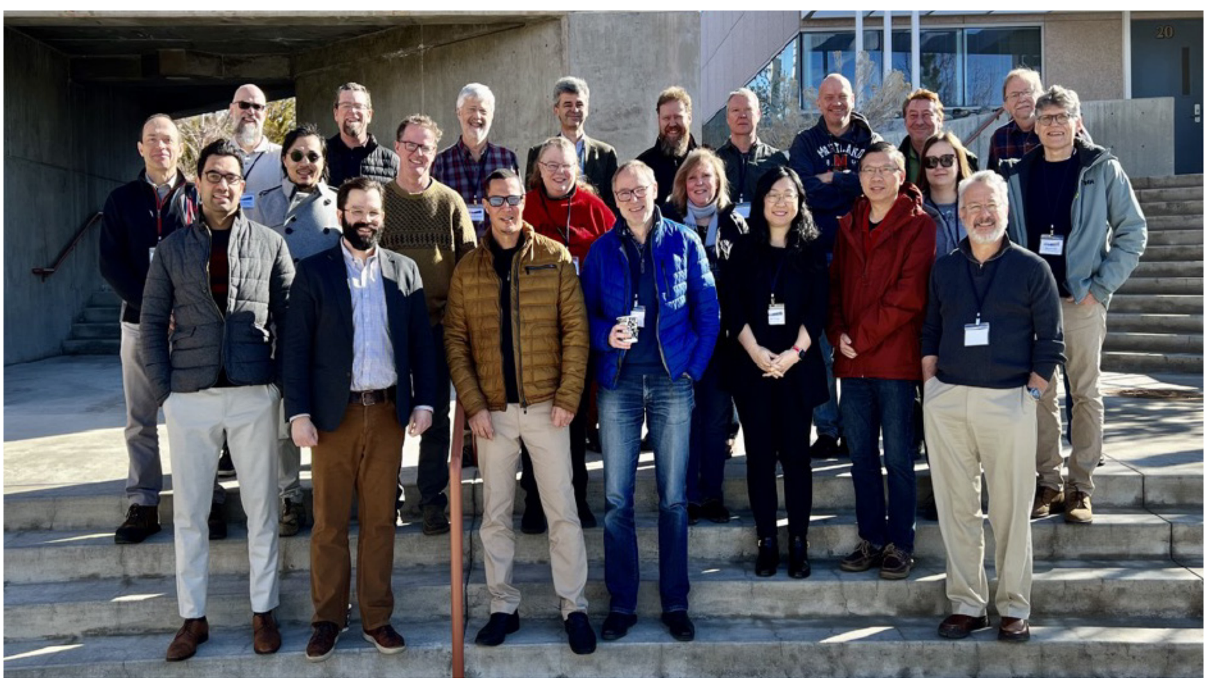

Photo 1. The Landsat Science Team at the 2023 Landsat Science Team Meeting held at the Desert Research Institute (DRI) in Reno, NV. **Photo credit:** Public Doman

compatibility with international and commercial data to enable new applications.

The 2018–2023 LST consisted of two agency cochairs, two academic coleads, and 21 other members. **Jeff Masek** [NASA's Goddard Space Flight Center (GSFC)—*Landsat Project Scientist*] served as the NASA cochair until his retirement in June 2022. **Chris Neigh** [GSFC—*Landsat Project Scientist*] assumed this position in July 2022. **Chris Crawford** [U.S. Geological Survey's Earth Resources Observation and Science (EROS) Center—*Landsat Project Scientist*] served as the USGS cochair. **David Roy** [Michigan State University (MSU)] and **Curtis Woodcock** [Boston University (BU)] served as the academic coleads. A complete list of **2018–2023 LST members** can be found on the Landsat mission website.

From the summer of 2020 to February 2022, the LST moved their biannual meetings to a virtual format due to the COVID-19 pandemic. In-person meetings resumed in August 2022. The remainder of this article provides an overview of the August 2022 and the February 2023 meeting. The article ends with a "Summary of the Final Recommendations of the 2018–2023 LST," on page 42. Meeting agendas, objectives, and presentations can be found at on the **Landsat mission website**.

August 2022 Meeting

The LST met at the USGS EROS Center in Sioux Falls, SD, from August 9–11, 2022, to regroup as the pandemic waned. The goals of this meeting were to honor LST members who had retired or passed away, update the team on Landsat 9 operations since launch, address forthcoming changes to Landsat Collection 2 (C2) Level-2 products, highlight science applications and advancements, and participate in the Landsat 9 Mission Transition Handover.

On the first day of the meeting, **Pete Doucette** [EROS—*Director*] gave opening remarks, acknowledged the original pioneers of the EROS and Landsat programs, and presented an update on EROS staffing and budgets. **Tim Newman** [USGS National Land Imaging (NLI) Program—*Program Coordinator*] reflected upon the fiftieth anniversary of Landsat and the launch of Landsat 9 on September 27, 2021; summarized the operations of Landsat 8; and discussed the status and future of the Sustainable Land Imaging (SLI) Program, including aspects of the updated NASA–Department of Interior (DOI) interagency agreement and plans for Landsat Next.

Chris Crawford joined **Keith Alberts** [EROS] in providing Landsat mission updates. Alberts outlined the status of the three operational missions and provided scene acquisition summaries. Crawford discussed the details of the extended Landsat 7 science mission, noting that Landsat 7 was lowered from 705 km (438 mi) to 697 km (434 mi) on April 6, 2022, and resumed science imaging on May 5, 2022. **Cody Anderson** [EROS] provided calibration and validation updates for data from instruments on Landsat 8 [Operational Land Imager (OLI) and Thermal Infrared Sensor [TIRS] and Landsat 9 [OLI-2 and TIRS-2] and called attention to recent publications about Landsat 9 cross-calibration with Landsat 8 and early on-orbit imaging performance. **Chris Engebretson** [EROS] discussed Landsat 9's initial data processing approach, postlaunch reprocessing events, and future reprocessing needs to incorporate first-year adjustments.

Saeed Arab [EROS/KBR, Inc.] presented details about the upcoming changes to Collection 2, Level-2 (L2) data. He discussed how the end of Moderate Resolution Imaging Spectroradiometer (MODIS) science observations will impact the Landsat 8/9 Land Surface Reflectance Code (LaSRC) Surface Reflectance product.[3] Arab indicated that the Visible Infrared Imaging Radiometer Suite (VIIRS)[4] Climate Modelling Grid (CMG) products can and will serve as an alternative source of ozone and water vapor data. He also referenced the upcoming processing changes to Landsat 8/9 Surface Temperature products as a result of plans to replace the Goddard Earth Observing System (GEOS)-FP IT system with a new system named GEOS-IT.

The first day of the meeting concluded with a celebration of life that recognized the incredible contributions of **John Dwyer** and **Tom Loveland** [both from EROS]. **Dwyer**, who passed away on July 4, 2021, was the former USGS Landsat 8 Project Scientist and Science and Applications Branch Chief at EROS. After 39 years at the EROS, he retired in 2019. He was instrumental in establishing Landsat as an operational program, and he was proactive in increasing the breadth and depth of science applications through the development of the Land Satellites Data System (LSDS) Science Research and Development (LSRD) project team. Dwyer navigated through volumes of data with sophistication and intellect in unprecedented times. **Loveland**, who passed away on May 13, 2022, was the Chief Scientist and a research geographer at EROS—and longtime author of LST summaries for *The Earth Observer*. He dedicated his USGS career of public service to advancing the use of Earth observation data for natural resources management and scientific understanding. He became a globally recognized remote sensing scientist, received

[3] MODIS instruments fly on NASA's Earth Observing System Terra and Aqua platforms. Both mission will end in the next few years and plans are underway for continuity of MODIS data products.

[4] VIIRS instruments fly on the Suomi National Polar-orbiting Platform (Suomi NPP) and on the National Oceanic and Atmospheric Administration's (NOAA) -20 and -21 satellites.

a Pecora Award in 2018, and served as the USGS cochair of the LST from 2006–2018. Together, Dwyer and Loveland were an unmatched force. Their dedication, expertise, and contributions, which will live on in perpetuity, were appreciated and memorialized during the LST celebration.

During the second day of the meeting, several presenters shared their applied science projects and perspectives. For brevity, a few presentations have been selected that might be of particular interest to readers, however a **complete list of presentations** is available. **David Johnson** [USDA National Agriculture Statistics Service] gave a presentation on crop type mapping and discussed the need for and possibility of developing global crop datasets using temporally dense Landsat and Sentinel-2 composites and machine learning. **Noel Gorelick** [Google Switzerland] provided an overview of how the Google Earth Engine has used a decade of Landsat data, underscoring that a large percentage of registered users integrated Landsat data into their scripts and models.

Mike Wulder [Canadian Forest Service] discussed the use of Landsat data to map and monitor Canada's forested ecosystem. He emphasized that Landsat data has the required characteristics to develop high-quality land cover data products, support forest inventories, track disturbances, and generate carbon accounting budgets. **Curtis Woodcock** and his fellow BU researchers presented a framework for developing near real-time tropical forest disturbance models using fused data from multiple sensors, including those from Landsat and from the European Space Agency's Copernicus Sentinel-2 and Sentinel-1 missions.

The August 2022 meeting concluded with the Landsat 9 Mission Transition Handover Ceremony as administrators, EROS employees, scientists, researchers, faculty from South Dakota State University, and representatives from AmericaView and media outlets joined together to celebrate the official commencement of Landsat 9 operations. NASA transferred ownership and operational control of the Earth-observing satellite system to the USGS, and **Pete Doucette** signed the Landsat 9 Certificate of Readiness—see **Photo 2** *below*.

February 2023 Meeting

The 2018–2023 LST met for their final meeting at the Desert Research Institute (DRI) in Reno, NV from February 7–9, 2023. **Justin Huntington** [DRI] hosted the event and gave opening remarks about the history of the research facility and its involvement in managing Nevada's arid land resources. He emphasized the value of Landsat data in solving the hydrologic problems of the Intermountain West and Colorado Plateau through updates to agricultural models and perennial yield estimates.

Tim Newman presented an NLI Program summary, highlighted the Senate resolution (S. Res. 721) that

Photo 2. NASA, DOI, and USGS officials pose with a key symbolizing the longstanding NASA–USGS Landsat partnership's goal of "Unlocking Answers, Revealing Our Changing Earth," after signing the Landsat 9 Certificate of Readiness. They include [*left to right*]: **Mike Egan** [NASA HQ—*Program Executive*], **Cathy Richardson** [NASA GSFC—*Deputy Director for Flight Projects Directorate*], **Pete Doucette** [USGS—*EROS Director*], **Tanya Trujillo** [DOI—*Assistant Secretary for Water and Science*], **Paul TenHaken** [*Mayor of Sioux Falls*], and **David Applegate** [USGS—*Director*]. **Photo credit:** Ginger Butcher/SSAI

celebrated Landsat's Fiftieth anniversary, provided Landsat mission updates, and discussed the SLI Program, including second phase activities and budgets. The Landsat mission updates in the Resolution focused on the extended science mission of Landsat 7, the tenth anniversary of Landsat 8 (February 11, 2023), and the continued operations of Landsat 9. **Mike Egan** [NASA—*Flight Program Executive (FPE)*] discussed the status of Landsat Next and the future phases of the SLI Program, including the need for a new architecture study team and a technological assessment for future Landsat missions.

Pete Doucette presented an update on EROS, including the upcoming fiftieth anniversary of the EROS in August 2023. He also presented an organizational overview and gave an update on funding resources and distributions. In terms of Landsat operations, he discussed the receiver anomaly issues associated with Landsat 8, station keeping and risk mitigation maneuvers, and cloud-hosting solutions for Landsat data.

Saeed Arab and **Tom Maiersperger** [EROS] gave an overview of the known issues associated with Landsat C2, L2 data, including those impacting the quality of Landsat 8/9 Land Surface Reflectance Code (LaSRC), Landsat 4–7 Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) Surface Reflectance, and Landsat 4–9 Surface Temperature. The presenters acknowledged that the USGS is working to fully characterize and document these issues, identify the impacts on final data products, and develop procedures and algorithms to improve data archive processing.

On the second day of the meeting, **Bruce Cook** [GSFC—*Landsat Next Project Scientist*], **Jim Pontius** [NASA GSFC—*Landsat Next Project Manager*], and **Brian Sauer** [EROS—*Landsat Next Project Manager*] presented a comprehensive overview of the Landsat Next mission concept, objectives, and status. The presenters emphasized that the mission will markedly increase scientific performance, employ rigorous calibration techniques, and ensure the sustainability of long-term mission operations. They further outlined important milestones, including the successful completion of the Mission Concept Review, advancement into Phase A, the release of the Landsat Next Instrument Suite (LandIS) Request for Proposal, and upcoming integration and ground system studies. More information is available on the **Landsat Next** website.

Chris Engebretson and **Doug Daniels** [EROS—*Landsat Next Chief Engineer*] provided a summary of the key technical challenges associated with Landsat Next—including increased data volumes and compression techniques, westward tilt trade studies, and high-latitude observational density. They addressed the need to identify an optimal data downlink capacity, compression scheme, and image acquisition strategy during Phase A activities.

Eric Vermote [NASA GSFC] provided an update on atmospheric correction over land, focusing on the validation of the LaSRC algorithm. **Nima Pahlevan** [GSFC/Science Systems and Applications, Inc. (SSAI)] continued with an update on atmospheric correction over water. He highlighted the challenges of aquatic remote sensing and the need for a global multi-mission framework to support validation practices and the development of harmonized aquatic science products. **Zhe Zhu** [University of Connecticut] and **Sergii Skakun** [University of Maryland] discussed cloud detection and masking procedures, including the Function of Mask (Fmask) and Cirrus cloud mask (Cmask) algorithms. They further summarized the results of the Cloud Mask Intercomparison eXercise (CMIX), an international collaborative effort that compares cloud detection algorithms.

Glynn Hulley [NASA/Jet Propulsion Laboratory (JPL)] and **Martha Anderson** [USDA Agriculture Research Service (ARS)] gave an update on the status and issues of Landsat L2 Surface Temperature products, noting that C2 interpolation methods introduce blockiness and emissivity artifacts. They suggested that future processing methods will be able to integrate global emissivity datasets from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on Terra, the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS), and the Combined MODIS/ASTER Emissivity over Land (CAMEL), to reduce artifacts and improve coverage in regions with persistent clouds.

At the close of the second day, **Lin Yan** [MSU] identified the need to improve Landsat 1–5 Multispectral Scanner (MSS) data processing to enhance geometric correction. He stressed the value of developing new algorithms to increase the feasibility of including MSS data in the Analysis Ready Data (ARD) products. He explained how an updated transformation (i.e., radial-basis-function) can be employed to increase the percentage of well-registered MSS images. **David Roy** offered some concluding remarks about the need for long-term consistent multi-sensor global ARD products and demonstrated some global Web-Enabled Landsat Data (WELD) ARD prototypes.

On the second evening, at an organized dinner, the LST recognized **Jim Irons** [GSFC—*Director Emeritus Earth Sciences Division*] and **Jeff Masek** for their valuable contributions to the Landsat Program. **Irons**, who retired in 2022, dedicated his career to studying the Earth as an integrated system. Among his many achievements and positions, he served as Landsat 7 Deputy Project Scientist from 1992–1999, Landsat 8 Project Scientist from 1999–2021, and agency cochair for the 2012–2017 LST. **Masek**, a research scientist with interests in forest dynamics and advanced remote sensing analysis, served as Landsat Data Continuity Mission (LDCM) Deputy Project Scientist from 2001–2010, Landsat 9 Project Scientist from 2010–2022, and colead of the LST from 2018–2022. He also led the LEDAPS project that utilized Landsat data to compile the first 30-m (~98-ft) resolution map of North American forest disturbance.

On the third and final day of the meeting, LST led a discussion about data quality improvements, Landsat Collection 3 priorities, and Landsat Next science requirements. The dialogue consisted of a solid recommendation to rectify C2, L2 Surface Reflectance, and Surface Temperature product issues as well as reprocess Landsat 9 data with the latest calibration coefficients. EROS completed reprocessing of Landsat-9 data in May 2023. The L2 Surface Reflectance and Surface Temperature products will be addressed in the future with Collection 3 (C3). There was another suggestion to align the processing of the Harmonized Landsat Sentinel-2 (HLS) data with Landsat Surface Reflectance improvements and Sentinel-2 updates. For the future C3, several team members encouraged the development of improved cloud detection algorithms and the integration of Landsat MSS into the CONUS/Alaska/Hawaii ARD products.

Final Recommendations of the 2018-2023 LST

As the 2018–2023 LST concluded its work, they recommended prioritizing the following three recommendations to propel the Landsat Program into the future and ensure a high-quality data archive.

Within 6-months. The LST recommended focusing on rectifying issues (i.e., atmospheric overcorrection and emissivity artifacts) with the C2, L2 products.

Within one year. The LST recommended focusing on feasibility investigations, developing decision-making frameworks, and analyzing data quality improvements. These efforts should include two investigations: (1) to evaluate the inclusion of Antarctic regions in the C2, L2 Surface Temperature product and (2) to assess the inclusion of cloud shadow data over water classes to support Cloud Mask algorithm validation. In addition, the LST suggested that a process be outlined when making mid-collection changes. Lastly, the LST encouraged a formal policy discussion about the use of *golden tiles*—locations that represent the range of atmospheric and surface conditions that can be used to evaluate land and aquatic science products and quantify data discrepancies between Landsat collections.

Beyond one year. The LST recommended a focus on data quality enhancements and research and development activities. In addition, MSS in ARD data processing should be included and the cloud and atmospheric correction algorithms through international collaborations (e.g., CMIX) refined. Myriad research and development activities were recommended for C3 to address needs, priorities, and improvements. Specific activities should evaluate adjacency corrections; atmospheric correction over inland and coastal waters; cloud and cloud shadow detection; geodetic accuracy criterion; topographic correction using the Copernicus DEM (COP-DEM); Landsat global ARD; and *bidirectional reflectance distribution function* (BRDF)[5] minimization. One final recommendation was made to develop two *Landsat Next datasets*—a proxy dataset based on satellite data and simulated dataset based on modeling—to support Landsat Next science algorithm development and code for processing data.

Conclusion

The LST meetings provide a public forum for discussing the state and future of the Landsat Program. With over 50 years of Earth observations, the Landsat data archive provides the most comprehensive and continuous record of terrestrial land, coastal, and aquatic monitoring data. It serves as an indispensable medium-resolution, Earth-observation resource for evaluating human impacts and environmental changes. With Landsat Next planning and formulation underway, the Landsat Program will march toward a new era of remote sensing through innovative technologies and expanded observational capabilities. ■

[5] The *bidirectional reflectance distribution function* (BRDF) defines how light is reflected at an opaque surface. In remote sensing it's used for correction of view and illumination angle effects (e.g., in image standardization and mosaicking), for deriving albedo, for land cover classification, for cloud detection, and for atmospheric correction.

Update on the State of CERES and Highlights from Recent Science Team Meetings

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Introduction

Since the last update on the Clouds and the Earth's Radiant Energy Systems (CERES) in *The Earth Observer*,[1] there have been three CERES Science Team Meetings (STMs) held. Owing to continued concerns over COVID, the first two meetings—October 12–14, 2021 (hereinafter Fall 2021)) and April 16–28, 2022 (Spring 2022)— were held virtually with NASA's Langley Research Center (LaRC) acting as the online host. The third was an in-person meeting held at LaRC from May 9–11, 2023 (Spring 2023). **Norman Loeb** [LaRC—CERES *Principal Investigator (PI)*] hosted all of these CERES meetings.

Although there was no CERES STM held in the Fall of 2022, there was an in-person international Earth Radiation Budget Workshop held October 12–14, 2022, at the Max Planck Institute (MPI) in Hamburg, Germany, with **Bjorn Stevens** [MPI—*Director*] serving as host. Participants at this meeting included representatives from the science teams of current and future Earth Radiation Budget (ERB) instruments including: CERES, NASA's **Libera** mission,[2] the European Organisation for the Exploitation of Meteorological Satellites' (EUMETSAT) **Geostationary Earth Radiation Budget** (GERB) instrument,[3] and the French Centre Nationale d'Études Spatiales' **Scanner for Radiation Budget** (ScaRab).[4]

The next section presents a summary of the current status of the CERES mission—drawing primarily from the *State of CERES*, programmatic, and mission and instrument status reports delivered at the meetings listed above. The content includes updates on the status of the platforms that carry CERES instruments, CERES data products and algorithms, and CERES outreach activities. Subsequent sections contain summaries of the invited science presentations given at these meetings, followed by selected contributed science presentations from each meeting. More information on topics briefly mentioned in the summary from the meetings, contained in their presentations, is available on the **CERES website**.

State of CERES

To start each CERES STM, the CERES PI (**Norman Loeb**) outlined the major objectives, which remain similar from meeting to meeting. The specific objectives included:

- reviewing the performance and calibration of all CERES instruments—it was reported that there has been no change in their health and calibrations remain consistent;
- presenting changes in the Terra and Aqua orbits and their drift from their historical Mean Local Equatorial (MLT) crossing times and the response to those changes;
- highlighting key changes for Edition 5 products, including Global Modeling and Assimilation Office (GMAO) atmospheric reanalysis, new Moderate Resolution Imaging Spectroradiometer (MODIS) Collection 7, and code and algorithm improvements to enable seamless transition across satellite platforms;
- demonstrating the progress on Terra and Aqua Edition 5 development;
- summarizing key scientific research resulting from the CERES data; and
- discussing data product validation.

The content of the subsections that follow expands on this list of objectives.

Future of Terra and Aqua and Impacts on CERES

The 2023 budget terminates funding for Terra and Aqua science as of October 2023—even though both mission have fuel to last at least through 2026. An additional concern is the availability of National Oceanic and Atmospheric Administration (NOAA) Suomi National Polar-orbiting Partnership (NPP) data once

[1] To read the previous report, see **Summary of the Thirty-First CERES Science Team Meeting** in the July–August 2019 issue of *The Earth Observer* [**Volume 31**, **Issue 4**, pp. 23–26].

[2] Libera was selected as the first Earth Venture Continuity (EVC-1) mission, as established by the **second Earth Science Decadal Survey**. In essence, it is a follow-on to CERES (and thus named after the daughter of Ceres in Greek mythology), intended to continue the long-term Earth Radiation Budget time series beyond CERES and is planned for launch in 2027 on the Joint Polar Satellite System–4 (JPSS-4) satellite.

[3] GERB instruments fly on EUMETSAT's Metosat-8, -9, -10, and -11 satellites.

[4] ScaRab most recently flew on the joint Indian Space Research Organisation (ISRO)–CNES Megha-Tropiques mission from 2011–2014. Prior to that ScaRab flew on two Russian satellites in 1994 and 1998–2002.

NOAA-21 is operational.[5] The possible loss of these three platforms, each with one or more CERES instruments onboard, greatly increases the risk of having a gap in ERB measurements. (The next scheduled ERB instrument launch is Libera.)

The looming prospect of the Terra and Aqua missions ending at the end of Fiscal Year 2023 led to concerns in the user community. In response to these concerns, NASA Headquarters initiated a Request For Information (RFI) to determine the value of data collected during the Terra and Aqua drifting period. After the RFI, there was a workshop held in November 2022 to discuss its findings.[6] Specifically for CERES, collecting data as Terra and Aqua drift would allow running the instruments in Rotating Azimuth Plane (RAPS) mode to capture data at different solar zenith angles over zonal dependent surfaces to improve Angular Distribution Models (ADMs). The output from this drifting orbits workshop provided impetus for Terra and Aqua being included in the 2023 Earth Science Senior Review to determine if the missions should be extended three more years.

Although their exact end date is still to be determined, it is known that the Terra and Aqua data records will end at some point in the relatively near future, and follow-ons need to be established to ensure continuity of long-term climate quality data records. In recognition of this, a Terra, Aqua, and Aura Data Continuity Workshop took place May 23–25, 2023. Like the drifting orbits workshop, an RFI proceeded the continuity workshop, and the gathering provided a forum to discuss the results. Among the topics covered were EOS flagship mission data product continuity needs, capabilities of current missions to provide continuity, possible data gaps, and potential Earth Science Division (ESD) activities to minimize continuity losses after each mission terminates.

CERES Edition 5 Cloud Product Update

Discussions at recent meetings have focused on improvements made to the CERES Edition 5 cloud products. The atmospheric correction algorithm has been upgraded and steps are being taken to achieve consistency between measurements of cloud fraction and other cloud properties from the MODIS [on NASA's Terra and Aqua platforms] and the Visible Infrared Imaging Radiometer Suite (VIIRS) [on the joint NASA–NOAA Suomi NPP, NOAA-20, and -21 platforms] as well as with similar measurements from geostationary imagers. Currently, some cloud algorithms need specific thresholds for each platform-imager used. However, efforts are ongoing to eliminate the need for these unique thresholds.

New Global Cloud Composite Product Released

The new Global Cloud Composites (GCC) data product has been created, which is a 3-km (~1.9-mi) grid of combined radiances, cloud properties, and radiative fluxes compiled every 30–60 minutes. The NASA Satellite Needs Working Group funds the GCC, which is intended to serve modeling needs related to cloud parameterizations.

Angular Distribution Model (ADM) and Radiance Inversion Update

The CERES Suomi NPP version of ADMs has been developed using three years of RAPS data. The change in the global shortwave (SW) flux from the new ADM can be more than 1.5 W/m^2— mostly observed over snow and ice surfaces, which have significant cloud property differences between MODIS and VIIRS. The direct-integration check indicates that the global mean SW flux errors from Suomi NPP are 10–20% smaller than those same errors using Aqua ADMs on NPP radiances. The algorithm that corrects for the spectral response in the CERES instrument to produce "unfiltered radiances" has been improved by including more solar and view zenith angles from seasonal simulations of spectral radiances in the look-up table.

Energy Balance and Filled (EBAF) Product Update

As a result of an Aqua satellite anomaly in April 2022—related to the switch in satellite power controller in April 2022—the EBAF transition to NOAA-20 occurred with data in April 2022—three months earlier than planned when Aqua's drift was the only conern. The CERES team has been working on minimizing differences between the Terra-only, Terra and Aqua, and the latter NOAA-20 period. This has been accomplished by creating monthly regional climatologies that extend the Terra-only and NOAA-20-only data into the Terra-Aqua periods and determine the difference between the Terra and Terra-Aqua runs and likewise, NOAA-20 and Terra-Aqua means. These adjustments are then applied to when there is only one platform. The EBAF top of atmosphere (ToA) Edition 4.2 product was released in December 2022.

Various temporal and spatial discontinuities on the surface fluxes used in the EBAF Edition 4.1 product are caused by geostationary satellite cloud property artifacts. The processing for the new edition does not include geostationary clouds but does interpolate clouds

[5] Once NOAA-21 is operational, NOAA will designate Suomi NPP as the tertiary instrument (with NOAA-20 as primary and -21 becoming secondary) and plans to stop processing data from the Suomi NPP instruments. There are ongoing discussions to keep the instrument data flowing to NASA however.

[6] To learn more about this workshop, 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].

derived from the low-Earth orbit imager between overpasses. It also used the **Modern-Era Retrospective analysis for Research and Applications, Version 2** (MERRA-2) temperature and humidity profiles—due to discontinuities in the **Goddard Earth Observing System** (GEOS) 5.4.1 reanalysis caused by the loss of data from Aura's **Microwave Limb Sounder** (MLS). The same climatological adjustment for the ToA product was applied to the surface fluxes. Edition 4.2 of the EBAF was released to the public in March 2023.

NOAA-20 FlxByCldTyp Product Update

It is too challenging to use the same approach applied to EBAF to adjust the cloud fraction and fluxes in the corresponding NOAA-20 FluxByCldTyp product to align with the Terra and Aqua version now being produced. The differences in cloud fraction and properties measured by Aqua and NOAA-20 are the result of the difference in available imager channels on each instrument. Therefore, the pressure and optical depth bins capture a different footprint, which complicates determining the adjustment. FluxByCldTyp will be produced for the entire NOAA-20 record.

Analyses Using Machine Learning and Artificial Intelligence

Discussions at the meetings examined how artificial intelligence (AI) and/or machine learning (ML) could be used to repair bad scan lines in geostationary imager radiances, resolve day-and-night cloud optical property inconsistencies, remove solar terminator and sun-glint artifacts, and determine the makeup of multilayer clouds. In one example, researchers used an ML approach using the partial radiances distributed between cloud layer and clear in the CERES footprint to determine separate fluxes within the footprint for the FluxByCldTyp product. The preliminary results showed an improvement over the current multi-regression method used. The CERES observation coverage study showed that the a higher resolution 0.5° latitude and longitude grid could be used for CERES Level-3 products.

CERES Outreach Update

Numerous major U.S. and international media outlets picked up on a *Geophysical Research Letters* article, **Satellite and Ocean Data Reveal Marked Increase in Earth's Heating Rate**, that used CERES and ocean buoy data to quantify the difference between absorbed solar radiation and emitted infrared radiation. The NASA **Global Learning and Observations to Benefit the Environment** (GLOBE) Clouds Team—along with multiple CERES scientists—received the 2021 Robert H. Goddard Award—Outreach Teams for exceptional innovation reaching families and the public at home during the COVID-19 pandemic. This program matches citizen scientist and satellite cloud observations.

Invited Science Presentations

There were three invited presentations for the Fall 2021 CERES STM and two for each of the other meetings. The summaries for each appear below in chronological order. Two of the Fall 2021 talks addressed snow and ice products that were being considered for future CERES processing. The other presentations addressed equilibrium climate sensitivity (ECS) especially uncertainty in cloud and aerosol feedback and Earth energy imbalance (EEI).

Fall 2021 STM

Gregory Cesana [Columbia University/NASA Goddard Institute for Space Studies (GISS)] looked at observations to try to constrain the climate sensitivity that could be caused by doubling of atmospheric carbon dioxide (CO_2). Tropical low-cloud feedback explains a large part of the spread in climate sensitivity in the latest **Coupled Model Intercomparison Project 6** (CMIP6) model runs. Low clouds reflect sunlight back to space and result in cooling. Therefore, if global warming causes low clouds to dissipate, a positive feedback results, leading to more warming; however, if the warming results in more low clouds, a negative feedback weakens surface warming. Cesana used sea surface temperature (SST) and estimated inversion strength (EIS) observations to quantify changes in low cloud fraction. Rising SST reduced cloud cover; however, low cloud cover increases with tropospheric stability. Stratocumulus and cumulus clouds showed different sensitivities with stratocumulus being more sensitive. These cloud types are well separated globally. Although observed historical trends differ from the simulated changes, they trend in the same direction. Inferred feedback from historical data is about half of what model simulation shows, and the feedback is mostly from stratocumulus clouds. This questions both high and low ECS models but support those in the middle with ECS about 3.85 K compared to historical values of 3.47 K.

Walt Meier [National Snow and Ice Data Center (NSIDC)] provided insight into the passive microwave snow and ice products produced at NSIDC. Ice and water respond differently at various microwave wavelengths and polarization. NASA takes advantage of these differences to create a sea ice concentration product. These techniques tend to underpredict sea ice concentration during the seasonal melt and for thin ice. Meier reviewed the differences in results between Near-real-time Ice concentration and Snow Extent (NISE), the NASA Team Bootstrap, and the **NOAA Climate Data Record** (CDR)—with the NOAA CDR showing the best performance.

Walt Clark [NOAA's Ocean Prediction Center] presented information on the **Interactive Multi-Sensor Snow and Ice Mapping System** (IMS). This product is generated by the U.S. National Ice Center Organization using a combination of machine-processed data and human analysis. This product uses geostationary and polar-orbiting satellite imagery, polar microwave, U.S.-based land radars, and surface observations.

Spring 2022 STM

John Fasullo [National Center for Atmospheric Research (NCAR)] addressed the impact of increased biomass burning on climate. He compared the impact of COVID-19—where the decrease in aerosol burden showed up in the zonal average but had only minor impact on the net SW ToA flux. Whereas, the 2019–2020 Australian wildfires increased black carbon and sulfate aerosols and significantly decreased both net clear-sky SW and net total ToA flux on par with the radiative impact of a major volcanic eruption. Analysis of wildfires in the western U.S. since 1984 estimate that the burnt area is twice what would have been seen without climate change. The CMIP 6 version of the **Community Earth System Model Version 2** (CESM2) was used with representative biomass burning emissions to look at two different indirect cloud aerosols effects due to biomass variability, namely how increased aerosol concentration increased cloud condensation nuclei and how delayed precipitation extended cloud lifetime. The model results showed warming in the Northern Hemisphere reduced mean cloud droplet number and low cloud amount, particularly in the northeastern Pacific Ocean, and increased net surface SW flux.

Maria Rugenstein [Colorado State University] explained how the CERES observations shows albedo symmetry between the Northern and Southern hemispheres; however, most CMIP5 and CMIP6 model results do not reflect this symmetry in either the pre-industrial or CO_2-forced runs. The variation from symmetry has decreased in CMIP6. Rugenstein raised the question on what insight can be gleaned from changes in these models despite their bias. There was a strong correlation between the mean-state albedo symmetry and the CO_2-forced change and surface temperature difference. The CO_2-forced models showed an evolution to more hemispheric asymmetry that is well correlated to surface temperature differences between the hemispheres.

International ERB Workshop (Fall 2022)

Jean-Louis Dufresne [Laboratoire de Meteorologie Dynamique et Institut Pierre-Smone Laplace, France] calculated low-level cloud reflectance over the ocean using cloud fraction measurements from the **Cloud-Aerosol Lidar with Orthogonal Polarization** (CALIOP) instrument on the **Cloud-Aerosol Lidar and Infrared Pathfinder Satellite** (CALIPSO) and matched these data with reflectance measurements from the former **Polarization and Anisotropy of Reflectance for Atmospheric Science coupled with Observation from a Lidar** (PARASOL) mission. The researchers used sky reflectance to "back out" the cloud reflectance. When these results are compared to a subset of CMIP6 climate models, the models have higher amounts of low-cloud cover and are brighter. As lower tropospheric stability increases, both observations and models show an increase in cloud cover; however, where observations show an increase in cloud reflectance, the models show a decrease. He hypothesized that it might be due to the models only simulating small cumulus clouds at low levels and not the variety actually observed.

Bjorn Stevens [MPI] gave an overview on how cloud feedback assessment changed between the **Intergovernmental Panel on Climate Change** (IPCC) Fifth Assessment Report (AR5), published in 2014, and the Sixth Assessment Report (AR6), published in 2022. AR6 provided a more detailed breakdown of various types of clouds and their contributions. About 25% (or 0.8 K) of the warming in climate sensitivity can be attributed to clouds. Stevens evaluated the radiative response to changing CO_2 concentration in spectral space. The calculation using the simple clear-sky case with constant relative humidity yielded a climate sensitivity of 3 W/m^2. He then extended these concepts to include: 1) the effects of clouds, which dampen the clear-sky response to forcing; 2) the impact of clouds near the surface in deep moist tropical boundary layers, which enhance the response; and 3) the effect of high-clouds over deep moist regions in the tropics, which cause small increases. Spectral masking caused by greenhouse gas absorbers such as CO_2 and water vapor (H_2O_v) in specific bands block flow of surface flux, which has increased, from reaching space. Based on H_2O_v, the surface impact is limited to the atmospheric window of 8.3–12.0 µm. The increase of CO_2 increases the masking by ~1.5 µm—but replaces surface emissions with those from the tropopause. Cloud impacts occur across the spectrum and mask the radiative response to warming. These impacts either occur high in the troposphere where they mask the increase, or lower in the troposphere, where they set a colder baseline emission. Likewise, when cloud top emission temperature does not change, it will mask the surface window emissions.

Spring 2023 STM

Shiv Priyam Raghuraman [NCAR] addressed the large uncertainty in estimating future global warming seen in increased sensitivity of CMIP6 models to CO_2. Most of the uncertainty is related to the uncertainty range in cloud feedback. Together, clouds have a net cooling effect of -20 W/m^2. This leads to the question of why the 0.23 K per decade surface warming trend has not been seen in the satellite record of cloud radiative effect (CRE) estimated as -0.03 W/m^2 from CERES EBAF. Raghuraman divided the change in CRE into effective radiative forcing (ERF), warming-induced CRE, and internal variability. CERES shows both LW and SW CRE trends, -0.34 and 0.32 W/m^2 per decade respectively, are above internal variability and observational uncertainty, but they tend to cancel in the net. The LW CRE forcing trend is dominated by the greenhouse gas forcing but masked by clouds when they are present. Approximately half of the observed trend in SW CRE can be attributed to greenhouse gas forcing (0.09 W/m^2 per decade) and the other half to aerosol forcing (0.08 W/m^2 per decade). While models tend to underestimate the negative warming-induced LW change in CRE, the warming-induced SW falls within the observed range—but with too much variability across the models.

Gavin Schmidt [NASA GISS] related climate model predictions of increasing EEI with ocean heat content (OHC) rise and CERES observations. The magnitude of EEI depends on the climate sensitivity that would not likely be seen in the surface temperature response; however, a larger climate sensitivity would lead to higher rate of heat storage in the ocean. Large spatial gaps and multiple measurement systems made accurate assessment of OHC difficult in the 1980s. With the implementation of corrections for **expendable bathyhermograph** (XBT) artifacts, the deployment of **Argo buoys** (beginning in 1999), and the launch of the **Gravity Recovery and Climate Experiment** (GRACE, 2002) and its Follow-On (GRACE-FO, 2017), the relationship between observed and modeled OHC came into focus. The CERES net ToA radiation correlated well with the observed OHC. The CERES observation showed a big decrease in reflected SW and increase in outgoing LW, which models do not detect. The changes in the CERES observation trends occur after 2014—which is after the **Atmospheric Model Intercomparison Project** (AMIP) model runs in CMIP6. Schmidt proposed that aerosol changes and El Niño could be responsible for these differences that could be better understood with today's model quality and extending AMIP-style runs from 1990 to present using updated SST and **Community Emission Data System** (CEDS) sources. A limited modeling project classified as CERESMIP (similar to AMIP) is now underway that has the goal of providing better understanding of the CERES observations. Model results from CERESMIP are expected in the next year.

Contributed Science Presentations

The four meetings contained a variety of presentations that provided information on:

- validation of CERES products;
- CERES observations and models detecting increased radiative forcing;
- observations and models, especially in the Arctic and Tropics, measuring cloud and albedo radiation feedback;
- improvements in CERES algorithms and products;
- ERB instruments status update;
- explanation of inputs for CERES processing;
- the debate over Earth albedo hemispheric symmetry;
- impacts on CERES GMAO assimilation due to instrument loss; and
- validation efforts from field campaigns and independent measurements.

The presentations below are selected highlights from the four meetings.

Fall 2021 STM

Kory Priestley [LaRC] addressed the impact of CERES lunar observations on calibration. The Moon only fills between 7.4–9.7% of the CERES field of view with the remainder being 2 K deep space background—and providing a weak signal. The CERES instrument performs raster scans across the Moon as quasi-point source that has been used to validate the pre-launch alignment and interchannel relative pointing accuracy. The long-term lunar stability measurements are consistent with those measured by onboard calibration sources.

Seung-Hee Ham [LaRC/Science Systems and Application, Inc (SSAI)] enumerated changes in the updated CALIPSO, CERES, CloudSat, and MODIS (CCCM) product cloud algorithm. Selection of low cloud information from the three sensors reduced the amount of clouds detected and resulted in better computer SW fluxes from the previous version (see **figure 1** on page 48). The RelD1 CCCM was released in October 2021. Ham also showed validation of the Terra and Aqua Cloud Radiative Swath (CRS) ToA fluxes covering the period for January 2018–December 2022. The SW flux bias was 10 W/m^2, dominated by cloudy regions with almost no bias in cloud-free cases. The LW fluxes had a negative bias of 2 W/m^2, which doubled for cloud-free cases. The CRS provides top of atmosphere, atmosphere, and surface flux by using the Fu-Liou radiative transfer model and cloud information

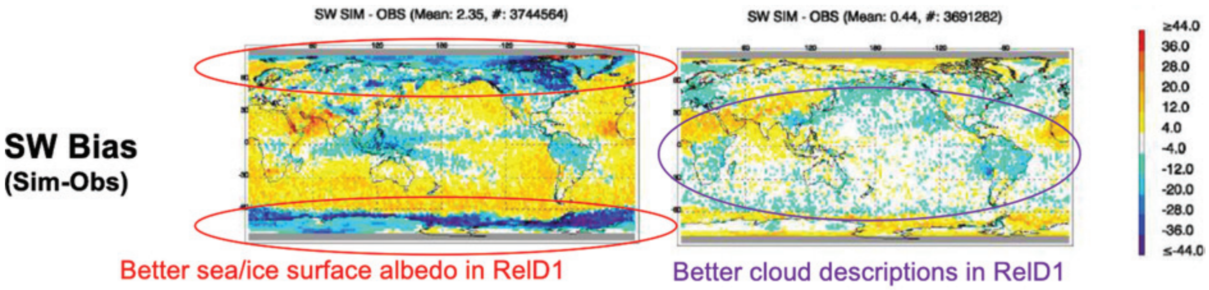

Figure 1. The difference between the calculated ToA SW flux and the observed CERES SW Flux from gridded CCCM footprints for the combined seasonal months (January, April, July, and October) 2008. The left figure is Release B1 and the right is Release D1. **Image Credit:** Seung-Hee Ham

for each CERES footprint. These products were released in April 2023.

Dongmin Lee [Goddard Space Flight Center (GSFC)] compared MODIS **Cloud Feedback Model Intercomparison Project** (CFMIP) Observation Simulator Package results with the CERES FluxByCldTyp product and identified differences. *K-mean clustering* was used to identify 11 cloud regimes. The daytime CERES–MODIS cloud fraction is globally larger (65% compared to 56% for those obtained from the simulator). Also, the frequency of cloud regimes differ between the model and observation.

Spring 2022 STM

Nadia Smith [Science Technology Corporation (STC)] provided an overview of the Community Long-term Infrared Microwave Combined Atmospheric Products System (CLIMCAPS). This product builds on the heritage of the Atmospheric Infrared Sounder (AIRS) Infrared and Microwave Sounder and applies it to Cross-track Infrared Sounder (CrIS) and Advanced Technology Microwave Sounder (ATMS) on Suomi NPP and NOAA-20 satellites. In addition to providing consistent temperature and water vapor profiles, it will include Outgoing Longwave Radiance (OLR) in Version 3.

Chris Macpherson [University of California San Diego Scripps Institution of Oceanography] used various CERES products to understand how increasing greenhouse gases and the resulting increase in downward LW flux would reduce the amount, height, and liquid water path of low stratus clouds thereby allowing more shortwave flux to reach the surface.

International ERB Workshop (Fall 2022)

J. Minnie Park [Brookhaven National Laboratory] examined the brightening over the Western North Atlantic Ocean. There is a robust decrease in aerosol optical depth (0.015 per decade) with corresponding decreases in low cloud fraction and optical depth. Park did not find significant changes in cloud microphysics from May to August—when the magnitude of decreasing trends in aerosol is greatest; however, changes did occur from October through March, when the trend is more muted. Negative trends in the *Twomey effect*—which describes how additional cloud condensation nuclei (CCN), possibly from anthropogenic pollution, may increase the amount of solar radiation reflected by clouds—are not seen in the downwelling surface solar radiance.

Spring 2023 STM

Marile Colon Robles [LaRC/SSAI] announced reaching the millionth match between **citizen scientist** cloud observations and satellite observations through the **GLOBE Clouds App-based Tool** since 2017.

Sunny Sun-Mack [LaRC/SSAI] described the neural network (NN) model development for nighttime cloud detection over Antarctica. The CALIPSO Vertical Feature Mask yields higher **cloud fraction** (average of 0.12 units more)[7] than the corresponding CERES Edition 4 MODIS cloud retrieval. The NN model uses the relative humidity profile, MODIS brightness temperature (T_b) at 3.7, 8.5, 11, and 12 mm, and the difference between the 3.7 and 11 µm bands and the 11 and 12 µm bands. The NN showed a 7–9% improvement in accuracy depending on season.

Lazaros Oreopoulos [GSFC] used the CERES FluxByCldTyp to decompose CRE by cloud types. He developed cloud radiative kernels based on the overcast and clear flux differences in each grid. Oreopoulos discovered that using only changes in cloud fraction with the kernel did not produce the observed change in CRE. He found good global agreement when he accounted for changes in the kernel, flux anomalies at overcast and clear-sky fluxes, and its covariance with cloud fraction change. The 2000–2019 trend showed weaker negative SW CRE values (less cooling) and weaker positive LW CRE values (less warming). Two-thirds of the observed SW CRE anomaly comes from there being fewer and optically thinner clouds. Overcast and clear-sky flux changes are the dominant

[7] Cloud fraction is a dimensionless quantity measuring the amount of cloud cover on a scale of 0 (Completely Clear) to 1 (Completely Cloudy).

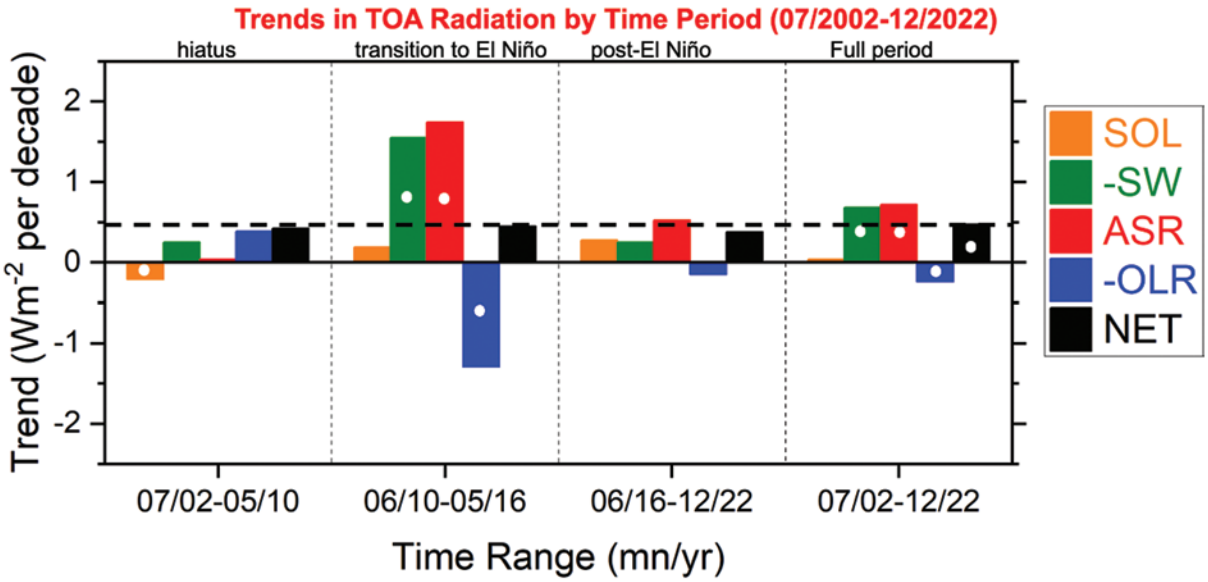

Figure 2. The trend in the Earth's energy imbalance as derived using CERES EBAF data for three distinct periods and the full period trend for July 2002–December 2022. Solar incoming (SOL), Shortwave Flux at Top of Atmosphere (SW), Absorbed Solar Radiation (ASR), Outgoing Longwave Radiation (OLR), and net (NET). The dotted line represents the full period trend of 0.47 W/m² per decade. **Image credit:** Norm Loeb/LaRC

contributors to the observed changes in LW CRE, whereas the cloud property anomalies cancel out.

Norman Loeb presented satellite and *in situ* observations that independently showed an approximate doubling of the EEI between mid-2005 to mid-2019. The period was marked by a decrease in clouds and sea-ice and an increase in trace gases and water vapor, which increases the rate of planetary heat uptake. The hemispheric symmetry in absorbed solar radiation (ASR) is impacted by decreases in the Southern Hemisphere due to low cloud changes that are balanced by larger decreases due to surface albedo in the Northern Hemisphere. Robust decreases in low and middle cloud amounts have been observed in both hemispheres. The **Figure** [*above*] shows how consistent the net flux trend is through various periods of internal variability even though the ASR and OLR trends vary during these periods.

Takmeng Wong [LaRC] presented an update for the Edition 4.1 Earth Radiation Budget Experiment (ERBE) Wide Field of View (WFOV) Nonscanner that provide fluxes on a 10° x 10° latitude/longitude product that has improved intercalibration with CERES, resolved additional time-space average data quality, and added 1999 data. When the ERBS data is combined with CERES to provide a 30-year record, the OLR and ASR trends are 1.80 and 0.13 W/m² respectively.

Conclusion

From October 2021 to May 2023, multiple presentations grappled with the impact of cloud and aerosol feedback on ECS using both observation and model data. Increased understanding of the EEI has been provided through radiation budget and OHC observations. The meetings highlighted the challenge of developing seamless climate records, improvements to critical inputs used in CERES products, and progress on improved algorithms for the next edition of these products. The drifting orbits of the long-time Earth Observing System (EOS) satellites have led to changes in EBAF, SYN1deg, CldTypHist, and FluxByCldTyp products to maintain stability. ML has been applied to address several challenges with CERES products. The exciting CERESMIPs project was publicized that will extend model runs to cover more of the CERES observation period.

The next CERES STM will be held at the LaRC, May 14–16, 2024. ■

In Memoriam: Nancy Gray Maynard (1941–2023)

Photo. Nancy near Tromsø, Norway in 2009. **Photo credit:** Jenn Gebelein

Nancy Gray Maynard, known to many in the Earth sciences community for her decades of compassionate and dedicated work at NASA and elsewhere, died on September 20, 2023, at the Mirabelle Senior Living complex in Miami, FL, in the presence of her loving daughter Jenn Gebelein. She was 82.

Nancy was born on April 18, 1941, in Middleboro, MA, to parents Clara Gray and Thomas Maynard, and grew up in New England. She received a Bachelor of Science degree in biology-chemistry from Mary Washington College in Fredericksburg, VA, in 1963, followed by a Master's degree in zoology from the University of Miami, FL, in 1967, and a Ph.D. in marine biology from the Rosenstiel School of Marine & Atmospheric Sciences (RSMAS) at the University of Miami, FL, in 1974. She was a Postdoctoral Fellow at Harvard University in 1975–1976.

Nancy's career spanned numerous organizations and subject areas. Before arriving at NASA, she worked for the U.S. Department of Interior's Alaska Outer Continental Shelf Office in Anchorage, AK, assessing potential effects of oil and gas development on the marine environment (1976–1978), was the Oil Spills Scientific Support Coordinator for a National Oceanic and Atmospheric Administration (NOAA) team of scientists responding to oil spills in Alaska (1978–1980) and the southeast U.S. (1980–1982), was a Policy Analyst at the White House Office of Science and Technology Policy (OSTP) working on U.S.–India science and technology cooperation (1982–1983), was a Staff Director of the National Academy of Sciences Board on Ocean Science and Policy (1983–1985), and was a National Research Council Resident Research Associate at Scripps Institution of Oceanography (1985–1987).

Nancy joined NASA in 1987, when she became Head of the Oceans and Ice Branch at Goddard Space Flight Center (GSFC) (1987–1988), then the Associate Chief for Research in the Laboratory for Oceans (1988–1989). She returned to OSTP for four and a half years as Assistant Director for the Environment (1989–1993) and then returned to NASA, this time to NASA Headquarters

(HQ), where she served both as Deputy Director of the Office of Mission to Planet Earth's Science Division (1993–1998) and as Director of the Earth Science Enterprise's Applications, Education, and Outreach Division (1998–2000).

Following her work at NASA HQ, Nancy returned to GSFC, where she served in a variety of roles, notably as Associate Director of Environment and Health (2000–2005), Director of the Office of Education's Initiative for the Blind (2004–2005), Project Manager for the NASA Tribal Colleges & Universities Project (2007–2012), and Senior Research Scientist in the Cryospheric Sciences Branch (2007–2012). She was passionate about increasing diversity and opportunities at NASA and elsewhere, as reflected most prominently in her Initiative for the Blind, to inspire and empower those with limited eyesight to consider opportunities in science, technology, engineering, and mathematics (STEM) careers, and in her work with Tribal colleges and universities. In the latter role, she provided NASA opportunities to Native American students, including on-campus internships, and when she found that many reservation-based students were unable to leave their families for the standard 10-week internship, she created an "externship" program designed to take NASA to the Native American communities instead of bringing the Native American students to NASA Centers. She also led an initiative to encourage the incorporation of Indigenous observations in the scientific study of climate change, and she ensured the inclusion of Indigenous perspectives in the U.S. National Climate Assessment Report and in assessments of the Intergovernmental Panel on Climate Change (IPCC).

As a Senior Research scientist, Nancy pursued her interest in the use of remote sensing to monitor environmental changes in the Arctic and examine their impacts on Indigenous peoples. This included work with Eurasian reindeer herders, aimed at improving their resilience to the impacts of climate change and oil and gas development on reindeer migration routes and pastures.

Following retirement from the civil service in 2012, Nancy became Emeritus at NASA and returned to the University of Miami as a visiting scientist at RSMAS.

Nancy is survived by her daughter Jenn Gebelein, her son-in-law Jamie Goodman, her grandson Jayden Goodman, her brother Elliott Maynard, and her partner Robert Corell. She is sorely missed by many whose lives she affected.

More information about Nancy's life and her impact on those who knew her is available at her friends and family **memorial webpage**.

Acknowledgments: *The Earth Observer* staff wish to thank **Claire Parkinson** [GSFC] for writing this *In Memoriam*, **Jenn Gebelein** [Florida International University] for providing the photo, and **Jack Kaye** [NASA HQ], **Jenn Gebelein**, and **Bob Corell** [Global Environment & Technology Foundation] for providing ideas and background materials. ■

In Memoriam: Robert J. "Joe" McNeal (1937–2023)

Photo: The "founders" of NASA's Tropospheric Chemistry Program, estimated to have been taken circa 1982.
[Front row, *left to right*]: Bob Duce, Doug Davis, Don Lenschow, Joe McNeal, Dan Albritton, Jarvis Moyer, and Reg Newell.
[Back row, *left to right*]: John Reller, Howard Kurfman, Helen Thompson, John Mugler, Dave McDougal, amd Jim Hoell.
Photo credit: James Crawford

Robert Joseph (Joe) McNeal was a prominent atmospheric scientist at NASA Headquarters (HQ) from 1979–2000. Following a National Science Foundation (NSF) post-doctoral fellowship at Harvard (1962–1963), Joe joined Aerospace Corporation and served as Head of the Atmospheric Kinetic Department. In 1978, Joe became the first Atmospheric Chemistry Program Director at the NSF, later moving to NASA HQ, where his primary responsibility was as manager of NASA's Tropospheric Chemistry program. He continued his interest in atmospheric chemistry and its impact on life on Earth. He held memberships in Sigma Xi, Phi Lambda Upsilon, the American Geophysical Union, and the American Physical Society. He is the author or co-author of over 100 scientific journal articles.

A major component of the Tropospheric Chemistry Program was the NASA Global Tropospheric Experiment (GTE), which Joe initiated using aircraft- and ground-based experiments. In a seminal paper on the program published in 1983, Joe stated that the intention of GTE was to ultimately "focus on global scale investigations of principal tropospheric chemical and transport processes with space-based measurement as a major tool." This vision continues to drive NASA's program to this day, and as predicted in that same article, "Many of the mission and design specifications for tropospheric chemistry measurements from space would be formulated on the basis of results of the aircraft studies, supported by extensive modeling."

GTE, which operated on five continents and devoted major coverage to uncharted areas over the Atlantic and Pacific Oceans, was dedicated to improving knowledge of global tropospheric chemistry and its implications for the biosphere, climate, and stratosphere. GTE was a major force in enhancing our understanding of the potential impacts of human activities on Earth's climate by providing some of the first data on chemical composition in areas that were affected by biomass burning and the rapid onset of industrialization in Asia. The missions Joe initiated typically involved active participation by scientists in the regions and both contributed to and benefited from the developing capability of satellite observations for the Earth's atmosphere, especially the troposphere, which was less well-studied from satellites than the overlying stratosphere.

Joe also served as the NASA HQ Program Scientist for the Upper Atmospheric Research Satellite (UARS) and the Earth Observing System (EOS) CHEM satellite, which was renamed Aura at the time it was launched in 2004. UARS was launched in 1991 from the Space Shuttle Discovery; it was an orbital observatory designed to study the Earth's atmosphere, particularly the protective ozone layer. Following its launch, Joe worked with other NASA HQ Research and Analysis Program Managers and members of the UARS Science Team to develop and implement a validation program for UARS measurements using a variety of ground-based, balloon-borne, and aircraft-borne instruments. Joe's passionate, articulate, and knowledgeable support for space-based measurements throughout their long development lifetimes was important to the evolution and ultimate success of both UARS and Aura.

Joe is survived by his wife of 60 years, Jean Pulis McNeal; two children, James Robert and Emily Christine McNeal; four grandchildren: Riley, Jay, Sydney and Nathan; a sister Linda McNeal Greer, and multiple nieces, nephews, and cousins.

More information about Joe's life and impact is available at his personal **memorial webpage.**

[1] McNeal, R. J., Mugler, J. P., Harriss, R. C., and Hoell, J. M. (1983), NASA global tropospheric experiment, *Eos Trans. AGU*, 64(38), 561–562, doi:**10.1029/EO064i038p00561-01**

Acknowledgments: *The Earth Observer* staff wish to thank **Anne Thompson** [NASA's Goddard Space Flight Center (GSFC), *Emeritus*], **Mike Kurylo** [GSFC], **James Crawford** [NASA Langley Research Center], and **Jack Kaye** [NASA HQ] for writing this *In Memoriam* and providing ideas and background materials. **James Crawford** also provided the photo. ■

NASA Shares First Images from US Pollution-Monitoring Instrument

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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*.

On August 24, NASA released the first data maps from its new instrument launched to space earlier this year, which now is successfully transmitting information about major air pollutants over North America. From its orbit 22,000 miles above the equator, NASA's **Tropospheric Emissions: Monitoring of Pollution** (TEMPO) is the first space-based mission designed to continuously measure air quality above North America with the resolution of a few square miles—see Figure on Front Cover of this issue. The science mission is a collaboration between NASA and the Smithsonian Astrophysical Observatory (SAO).

"Neighborhoods and communities across the country will benefit from TEMPO's game-changing data for decades to come," said NASA Administrator **Bill Nelson**. "This summer, millions of Americans felt firsthand the effect of smoke from forest fires on our health. NASA and the Biden-Harris Administration are committed to making it easier for everyday Americans and decisionmakers to access and use TEMPO data to monitor and improve the quality of the air we breathe, benefitting life here on Earth."

Observations obtained using TEMPO will significantly improve studies of pollution caused by rush-hour traffic, the movement of smoke and ash from forest fires and volcanoes, and the effects of fertilizer application on farmland. In addition, TEMPO data will help scientists evaluate the health impacts of pollutants and aid in the creation of air pollution maps at the neighborhood scale,[1] improving understanding of disparities in air quality within a community. Data will be shared with partner agencies that monitor and forecast air quality, such as the Environmental Protection Agency and the National Oceanic and Atmospheric Administration.

Launched in April 2023 aboard a Maxar Intelsat 40e satellite on a SpaceX Falcon 9 rocket, **TEMPO** makes hourly daytime scans of the lower atmosphere over North America from the Atlantic Ocean to Pacific coast and from roughly Mexico City to central Canada. The primary instrument is an advanced spectrometer that detects pollution normally hidden within reflected sunlight.

The first pollution maps released by NASA from the mission show concentrations of nitrogen dioxide (NO_2) gas from pollution around cities and major transportation arteries of North America. TEMPO measures sunlight reflected and scattered off Earth's surface, clouds, and atmosphere. Gases in the atmosphere absorb the sunlight, and the resulting spectra are then used to determine the concentrations of several gases in the air, including NO_2—see **Figure 1**.

[1] Producing data at the neighborhood scale was a topic of discussion during the "Keynote Panel Conversation" held as part of the History of NASA and the *Environment Symposium*, which is summarized beginning on page 5 of this issue.

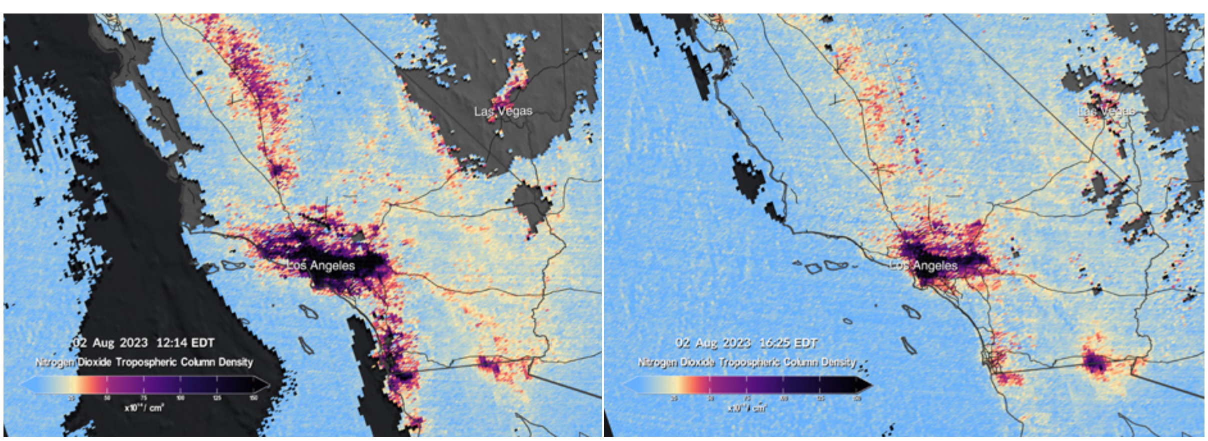

Figure 1. This pair of images—taken from a **visualization** covering a broader region (see **Figure 2** on page 55)—shows NO_2 levels over Southern California at 12:14 PM Eastern Daylight Time (EST) [*top*] and 4:24 PM EDT [*bottom*] on August 2, 2023, as measured by TEMPO. **Figure credit:** Kel Elkins, Trent Schindler, and Cindy Starr/NASA's SVS

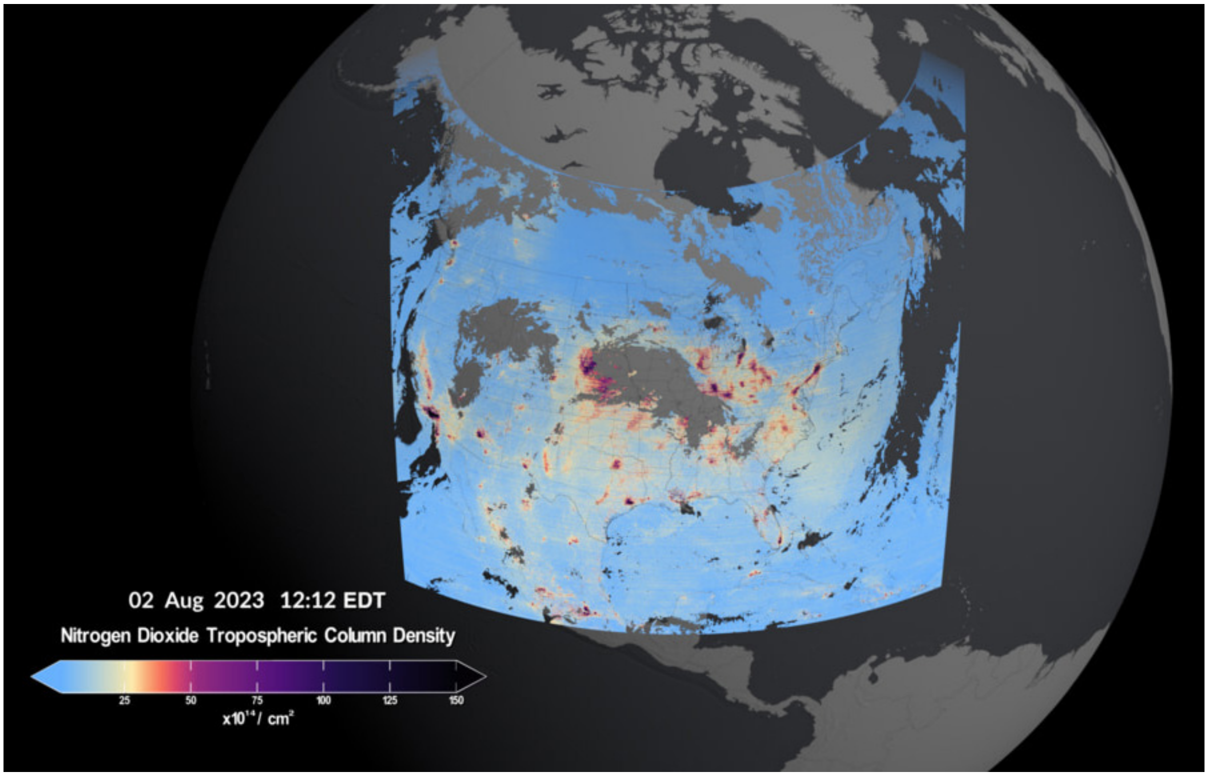

Figure 2. The **visualization** shows six scans made between 11:12 AM and 5:27 PM EDT on August 2, 2023. Closeup views focus on the southwestern U.S. from Los Angeles to Las Vegas; from central and eastern Texas to New Orleans; and the Interstate 95 corridor between New York and Washington, DC. The data were gathered during TEMPO's "first light" period from July 31 to August 2, when mission controllers opened the spectrometer to look at the Sun and Earth and start a variety of tests and solar calibrations. **Figure credit:** NASA SVS

"TEMPO is beginning to measure hourly daytime air pollution over greater North America," said **Kelly Chance** [SAO—*TEMPO Principal Investigator*]. "It measures ozone, nitrogen dioxide, formaldehyde, aerosols, water vapor, and several trace gases. There are already almost 50 science studies being planned that are based around this new way to collect data."

TEMPO's instrument was built by Ball Aerospace and integrated with the Maxar-built Intelsat 40e. Since launch, teams from NASA, Ball Aerospace, and SAO have been checking and calibrating the satellite's systems and components. The instrument began full operations in October, collecting hourly daytime scans, the first instrument to observe pollution over North America in this way.

"We are excited to see the initial data from the TEMPO instrument and that the performance is as good as we could have imagined now that it is operating in space," said **Kevin Daugherty** [NASA's Langley Research Center (LaRC)—*TEMPO Project Manager*]. "We look forward to completing commissioning of the instrument and then starting science research."

TEMPO is part of NASA's Earth Venture Instrument program, which includes small, targeted science investigations designed to complement NASA's larger research missions. The mission also forms part of a virtual constellation of air pollution monitors for the Northern Hemisphere, which also includes South Korea's Geostationary Environment Monitoring Spectrometer and European Space Agency's (ESA) Copernicus **Sentinel 4**.

Water-Watching Satellite Monitors Warming Ocean off California Coast

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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*.

The international **Surface Water and Ocean Topography** (SWOT) mission is able to measure ocean features, like El Niño, closer to a coastline than previous space-based missions. Warm ocean waters from the developing El Niño are shifting north along coastlines in the eastern Pacific Ocean. Along the coast of California, these warm waters are interacting with a persistent **marine heat wave** that recently influenced the development of Hurricane Hilary. The SWOT satellite is able to spot the movement of these warm ocean waters in unprecedented detail—see **Figure**.

A collaboration between NASA and the French space agency, Centre National d'Études Spatiales (CNES), with contributions from the Canadian Space Agency (CSA) and the UK Space Agency, SWOT is measuring the height of **nearly all water** on Earth's surface, providing one of the most detailed, comprehensive views yet of the planet's oceans and fresh water lakes and rivers.

Launched on December 16, 2022, from Vandenberg Space Force Base in central California, SWOT is now

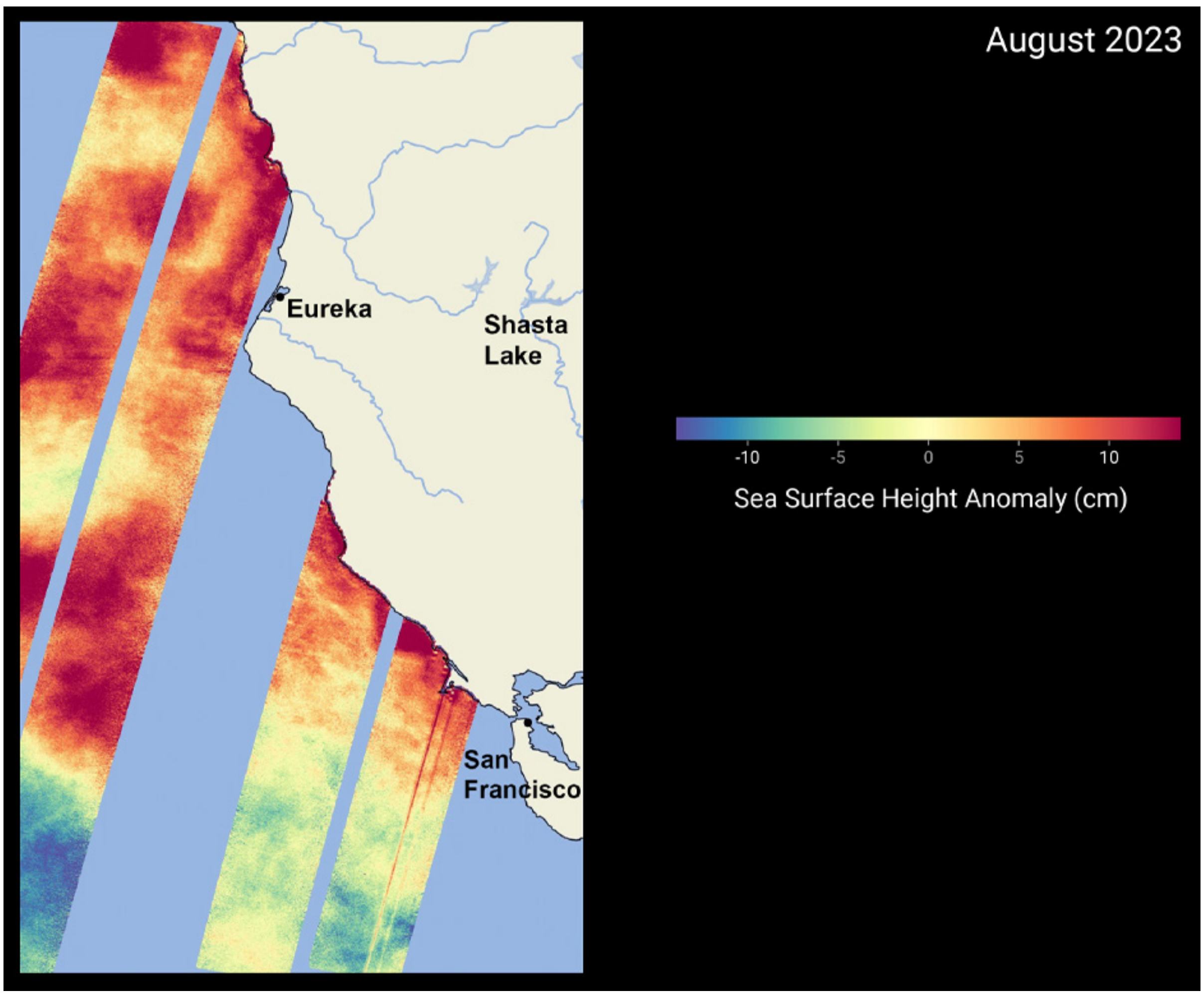

Figure. This data **visualization** shows sea surface heights off the U.S. West Coast, near the California–Oregon border, in August, 2023, measured by SWOT. Red and orange indicate higher-than-average ocean heights, due to a marine heat wave and a developing El Niño, while blue and green represent lower-than-average heights. The SWOT science team made these measurements with the Ka-band Radar Interferometer (KaRIn) instrument. With two antennas spread 33 ft (10 m) apart on a boom, KaRIn produces a pair of data swaths as it circles the globe, bouncing radar pulses off the water's surface to collect water-height measurements. The visualization combines data from two passes of the SWOT satellite. **Figure credit:** NASA/Jet Propulsion Laboaratory (JPL) in its operations phase, collecting data that will be used for research and other purposes. The JPL website has an **animation of the satellite unfolding itself**.

Water expands as it warms, so sea levels tend to be higher in places with warmer water. **El Niño**—a periodic climate phenomenon that can affect weather patterns around the world—is characterized by higher sea levels and warmer-than-average ocean temperatures along the western coast of the Americas.

"SWOT's ability to measure sea surface so close to the coast will be invaluable for researchers but also forecasters looking at things like the development and progress of worldwide phenomena like El Niño," said **Ben Hamlington** [NASA's Jet Propulsion Laboratory (JPL)—*Sea Level Researcher*].

In its September outlook, the U.S. National Oceanic and Atmospheric Administration (NOAA) forecast a greater than 70% chance for a strong El Niño this coming winter. In addition to warmer water, El Niño is also associated with a weakening of the equatorial trade winds. The phenomenon can bring cooler, wetter conditions to the U.S. Southwest and drought to countries in the western Pacific, such as Indonesia and Australia. ■

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*]

NASA Researchers Measure Sinking Land in American Samoa

Taylor Gilmore, NASA's Goddard Space Flight Center (GSFC)

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*.

On September 29, 2009, an 8.1-magnitude earthquake struck near American Samoa, Samoa, and Tonga, **triggering a tsunami** that caused human casualties and $200 million in property damage on the islands. The earthquake also exacerbated another problem in American Samoa: *subsidence*, or the sinking of land. When combined with relative sea level rise, land sinking can increase the frequency and amount of coastal flooding.

Using the island of Tutuila in American Samoa as an example—see **Figure**—a team of NASA scientists last year **published a study** in the journal *Geophysical Research Letters* (JGR) on how to better map ground changes on earthquake-prone islands. They found that using a combination of satellite and ground-based observations could result in a more nuanced and comprehensive map.

"Protecting against flooding on islands requires reliable measurements of how much the ground is sinking and where," said **Jeanne Sauber** [NASA's Goddard Space Flight Center (GSFC)—*Geophysicist*]. "You need to know in detail where the land is going down the fastest." Sauber and several NASA colleagues are combining remote sensing tools to figure that out.

Historically, subsidence measurements on small tropical islands have been difficult to make. Islands often have few resources for acquiring detailed measurements at the land surface, and dense midday clouds and vegetation can make good satellite data difficult to get.

In the past, scientists had used data from two points of measurement on Tutuila: a GPS station and the island's one tide gauge. They typically coupled those points with satellite altimetry, which allows scientists to broadly monitor the surface height of the ocean. But these data provided only a limited picture.

In the study, the researchers added InSAR, or interferometric synthetic aperture radar, which allowed them to see where the ground was changing. InSAR is a technique that involves comparing satellite radar images of the same area collected at different times to spot movement on Earth's surface and track changes in ground height.

Figure. Image of American Samoa's Tutuila Island, acquired on July 22, 2022, with the Operational Land Imager (OLI) on Landsat 8. **Figure credit:** NASA Earth Observatory/Lauren Dauphin

The study found that Tutuila sank an average of 0.24 to 0.35 in (6–9 mm) per year between 2015–2022 compared to 0.04–0.08 in (1–2 mm) per year before the 2009 earthquake. The highest rates of sinking occurred right after the earthquake, especially along the coastlines.

"We knew how much the ground is deforming at this one point because of the GPS station there, but with the radar remote sensing technique, we can get a much denser map of what's going on across the island," said **Stacey Huang** [GSFC—*Postdoctoral Fellow*], the study's lead author.

Building a Better Map

Synthetic aperture radar data are collected from planes or satellites. It works by sending out microwave pulses from the satellite to Earth's surface and then measuring the time it takes for the pulses to bounce back and the strength of that reflection, or *backscatter*. Unlike many satellite instruments, this kind of radar can pierce through clouds and dense vegetation, allowing researchers to accurately measure relative elevation and changes in the land surface. Huang and Sauber's study used data from the European Space Agency's (ESA) Copernicus **Sentinel-1A** satellite.

The researchers also used the French Centre National d'Études Spatiales (CNES) **Collecte de Localisation Satellite** (CLS) **Data Unification and Altimeter Combination System** (DUACS) (an operational multimission altimetry data production system) to assess sea level and correlate it with measurements from the island's Pago Pago tide gauge station. The gauge measured sea level relative to Tutuila, while the altimeter measured the absolute sea level. The difference between them shows, among other signals, Tutuila's land motion, or movement, relative to Earth's center.

One of the challenges for evaluating land subsidence on remote islands is understanding how the island motions may be influenced by the broader movement of tectonic plates. By including measurements from Tutuila's GPS station, the researchers could monitor the rate of vertical motion.

"So not only can we say what is one point doing relative to another on an island, we can say what is this island doing relative to other locations around the world," said Sauber, a co-author of the study.

Why the Land Sinks

Land subsidence in this part of the western Pacific Ocean results from the movement of the Pacific and Australian tectonic plates. When one plate passes under the other, a phenomenon called subduction occurs along the Tonga Trench, a deep canyon in the Pacific Ocean. Earthquakes frequently result from this process, creating vertical movement of the island's surface, along with ground-surface changes.

To understand how much the land has changed after each earthquake, scientists measure something called *vertical land motion*—the up-and-down movement of the land from the removal and rearrangement of materials in the Earth's subsurface.

"Over hundreds of thousands of years, or even millions of years, these volcanic islands tend to sink as they cool off," said **Eric Fielding** [NASA/Jet Propulsion Laboaratory (JPL)—*Geophysicist*]. "This long-term geologic process applies to the Samoan Islands, and the earthquake cycle adds to that."

"Sea level rise compounds the problem," said **Richard Ray** [GSFC—*Geophysicist*], the study's third author. In Tutuila, for example, the relative sea level is rising by as much as five times the global average according to a **previous study including Ray and Sauber**.

The average global sea level rose by 0.11 in (2.7 mm) from 2021 to 2022, according to a **NASA analysis of satellite data.** In that 2019 study, scientists found that the region's sea level rise relative to the land was 0.04 to 0.08 in (2–3 mm) per year before the earthquake, but now, relative sea level rise is several times the global average.

"Three millimeters may not sound like much, but it makes a difference over time as it builds up," Ray said.

Many islands around the world are facing rising sea levels and share similar features with Tutuila. Researchers hope to apply what they learned from Tutuila to other islands for coastal resilience planning, including **collaborative efforts** between NASA and the United Nations to inform decisions across Pacific Island nations.

Coastal resilience planning is necessary to protect people who live on smaller islands, and it requires reliable data on how fast the land is sinking. That's why scientists and planners are eager for 2024, when the joint NASA–Indian Space Research Organisation (ISRO) Synthetic Aperture Radar [NISAR] mission is slated to launch. NISAR will track movements of Earth's land and ice surfaces in extremely fine detail and will help identify and track vertical land motion around the world.

"We really need to know how fast that land is sinking so that policy decisions can be based on scientific data," Sauber said. "You do not want to move people away from their homes unless they're really going to be in a dire situation." ■

NASA Earth Science in the News

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

NASA, NOAA Proclaim the Twelfth Largest Single-Day Ozone Hole Since 1979, November 2, 2023, *techtimes.com*. In 2023, the Antarctic ozone hole reached its maximum size on September 21, NASA and NOAA **reported** based on their annual satellite and balloon-based measurements. This hole spans 10 million mi^2 (26 million km^2), and it stands as the twelfth largest single-day ozone hole since records began in 1979—see **Figure 1**. It is also the sixteenth largest when averaged from September 7 to October 13. Throughout the peak of the ozone depletion season, from September 7–October 13, this year's hole averaged 8.9 million mi^2 (23.1 million km^2)—roughly the expanse of North America.

"It's a very modest ozone hole," said **Paul Newman** [NASA's Goddard Space Flight Center—*Chief Scientist for Earth Sciences* and *Head of NASA's Ozone Research Team*]. He attributed this to diminishing levels of human-generated chlorine compounds, coupled with favorable Antarctic stratospheric weather that slightly ameliorated ozone levels this year. It is worth noting that the ozone layer functions as Earth's natural shield against the Sun's harmful ultraviolet radiation. A thinning ozone layer implies reduced defense against UV rays, potentially leading to sunburns, cataracts, and skin cancer in humans. Each September, the ozone layer depletes, forming an "ozone hole" over the Antarctic region. This term, however, does not denote a complete void of ozone but rather the area where ozone concentrations plummet below the historical threshold of 220 Dobson Units. The onset of ozone depletion was first reported in 1985, and levels have been closely monitored since 1979. NASA noted that the Montreal Protocol of 1987, followed by subsequent amendments, prohibited the global production of CFCs and other ozone-depleting substances by 2010. This concerted effort to curb emissions has resulted in a decline of ozone-destroying chemicals in the atmosphere and promising signs of stratospheric ozone recovery. ■

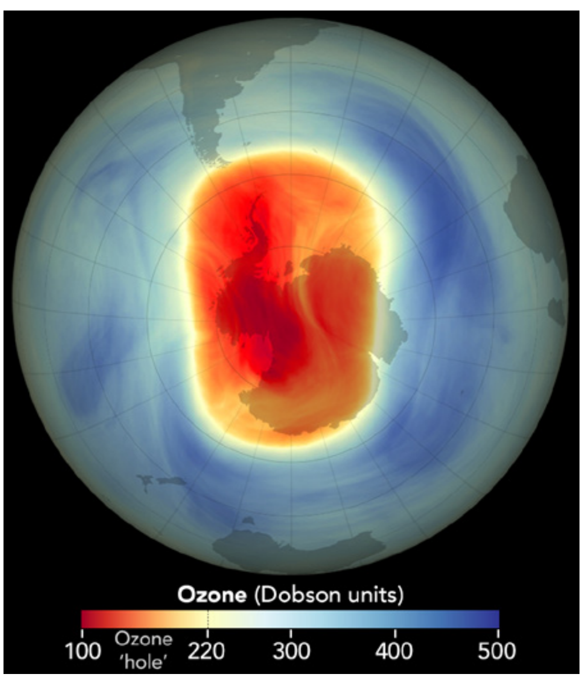

Figure 1: Displayed here is the extent and configuration of the ozone hole over the South Pole on September 21, 2023, at its peak, as computed by NASA Ozone Watch. Moderate ozone losses (*orange*) are visible amid widespread areas of more potent ozone losses (*red*). **Figure credit:** NASA Earth Observatory

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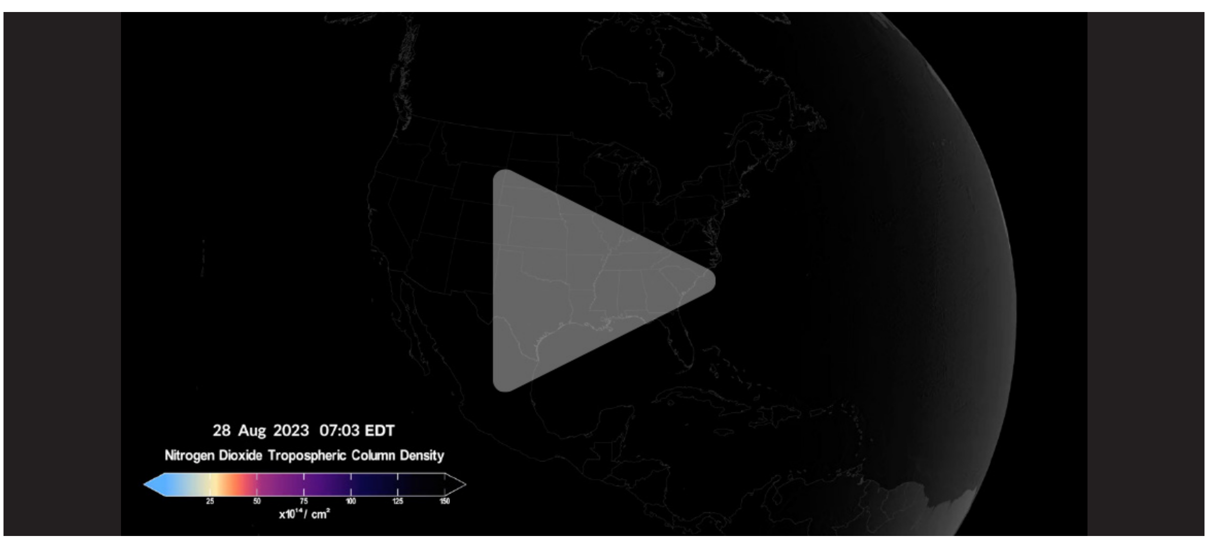
A Tale of Three Pollutants in Chicago: NASA-led Mission Looks to Help by Mapping Air Pollutants at a Neighborhood Scale, October 25, 2023, *phys.org*. Fine aerosol particles with diameters of 2.5 µm or less, called $PM_{2.5}$—which are more than 35 times smaller than a grain of sand and can infiltrate deep into lung tissue—are degrading air quality in neighborhoods that are already disproportionately exposed to fossil fuel emissions. These include neighborhoods located near highways, warehouses, and intermodal facilities, where freight-loaded trains and trucks converge. Thousands of such facilities are spread throughout the nation, and they are hot spots of diesel exhaust and nitrogen oxides (NO_x). Residents of communities downwind are breathing harmful air pollutants including $PM_{2.5}$, fossil fuel emissions, and smog. These pollutants move throughout the atmosphere and change by the hour, periodically exceeding the levels considered safe by the U.S. Environmental Protection Agency. While air quality monitors are distributed throughout the country, they are sparse in some regions—which means they cannot tell every neighborhood's story. A NASA mission aims to change that with new tools to monitor air pollutants from the streets to the stratosphere—see **Video**. ■

Video. NASA, NOAA, and other agencies worked together this summer through the Synergistic TEMPO Air Quality Science (STAQS) and Atmospheric Emissions and Reactions Observed from Megacities to Marine Areas (AEROMMA) missions to calibrate and validate NASA's new Tropospheric Emissions: Monitoring of Pollution (TEMPO) satellite, which is the first space-based instrument designed to continuously measure daytime air quality over North America at the resolution of a few square miles. The satellite and missions' combined aim was not only to better measure air quality, and the major pollutants that impact it, but also to improve air quality, from street to stratosphere. This effort was documented during the August 2023 campaign leg, which took place over the Chicago region. **Video credit:** Kathleen Gaeta/NASA

"Air pollution has dramatically improved across the U.S. in the past few decades due to environmental regulations, but some communities are still hot spots of poor air quality," said **Barry Lefer** [NASA Headquarters (HQ)—*Head of the Tropospheric Composition Program*].

STAQS included two Gulfstream jets equipped with state-of-the-art sensors and ground crews deployed in mobile research trailers across the country. At the heart of the mission were two overarching questions: *How do air pollutants change and move through the atmosphere,* and *which communities are disproportionately exposed?*

Data from TEMPO—see **Visualization**—combined with data from field campaigns like STAQS are giving scientists a more complete picture of the air pollutants that contribute to disease and premature deaths in the U.S. As as these data are gathered and analyzed, air pollution scientists will have details down to a level that matters to people on the street. The data will be freely accessible, according to Lefer, and particularly useful to researchers, state agencies, and local policymakers working to develop solutions. "The hope is that the detailed new data we're collecting will help communities make their air safer to breathe," Lefer said. ■



Visualization. NASA's Tropospheric Emissions: Monitoring of Pollution (TEMPO) instrument measures sunlight reflected and scattered off the Earth's surface, clouds, and the atmosphere. Gases in the atmosphere absorb sunlight, and the resulting spectra are then used to determine the amounts of several gases in the Earth's atmosphere, including nitrogen dioxide (NO_2). **Visualization credit:** Kel Elkins/NASA's Scientific Visualization Studio

Antarctica Logs 'Record-Smashing' Low for Sea Ice, Says NASA, September 26, 2023, *cnet.com*. Researchers from NASA and the National Snow and Ice Data Center (NSIDC) are tracking sea ice levels on both ends of the globe. A recent report shows that Arctic sea ice most likely reached its annual minimum extent on September 19—logging the sixth-lowest year based on records dating back to 1979. The news from the other pole was even more bleak. "Antarctic sea ice reached its lowest maximum extent on record on September 10 at a time when the ice cover should have been growing at a much faster pace during the darkest and coldest months," said NASA in a **statement**. In short, both regions are lacking ice—see **Figure 2**.

"While bright sea ice reflects most of the sun's energy back to space, open ocean water absorbs 90% of it," said NASA. "With greater areas of the ocean exposed to solar energy, more heat can be absorbed, which warms the ocean waters and further delays sea ice growth." Satellite data collected between March and September shows that Arctic ice cover shrank from 5.64 million mi^2 (14.62 million km^2) to 1.63 million mi^2 (4.23 million km^2). To put that in perspective, NASA said the lost sea ice could cover the entire continental U.S. ■

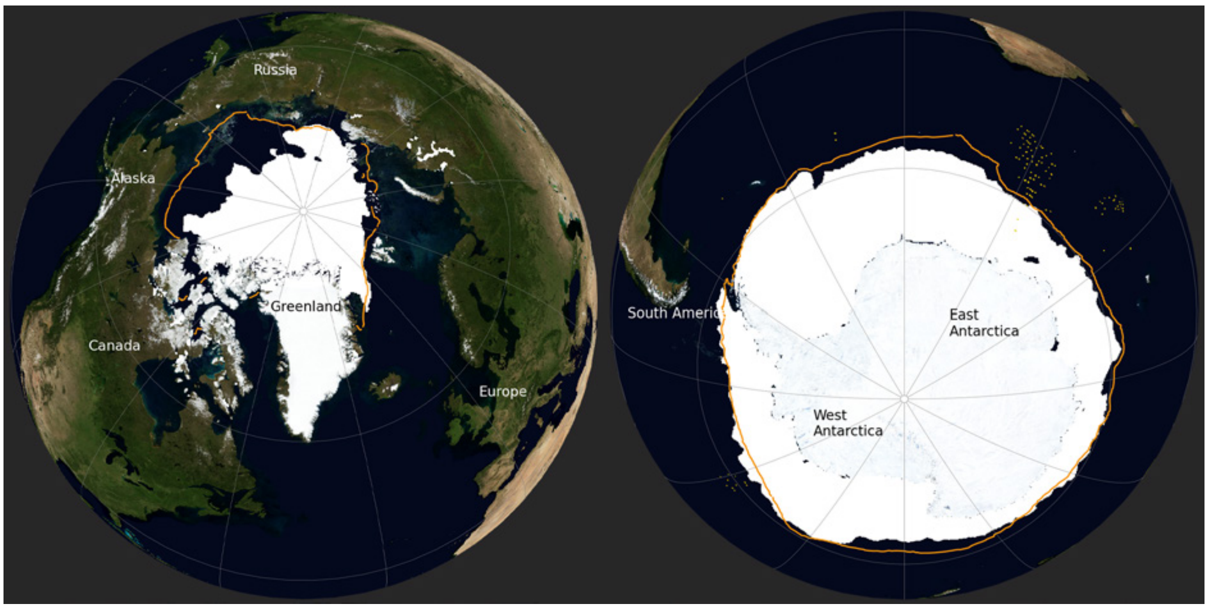


Figure 2. [*Left*] Arctic minimum sea ice extent on September 19, 2023; orange line indicates the median ice edge from 1981–2010. [*Right*] Maximum Antarctic ice extent reached on September 10, 2023; orange line indicates the median ice edge from 1981–2010. **Figure credit:** NSIDC/NASA Earth Observatory

Earth Science Meeting and Workshop Calendar

NASA Community

December 19–20, 2023
MISR Science Team Meeting
Pasadena, CA

Global Science Community

November 30–December 12, 2023
United Nations Framework Convention on Climate Change Conference of the Parties 28 (UNFCCC COP28)
Dubai, United Arab Emirates

December 11–15, 2023
AGU Fall Meeting
San Francisco, CA

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

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The Earth Observer

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Article submissions, contributions to the meeting calendar, and other suggestions for content are welcomed. Contributions to the calendars should contain date, location (if meeting in person), URL. Also indicate if the meeting is *hybrid* (combining online and in person participation) or *virtual* (online only). Newsletter content is due on the weekday closest to the fifteenth of the month preceding the publication—e.g., December 15 for the January–February issue; February 15 for March–April, and so on.

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