

The Earth Observer. March - April 2018. Volume 30, Issue 2.

## Editor's Corner

*Steve Platnick*

*EOS Senior Project Scientist*

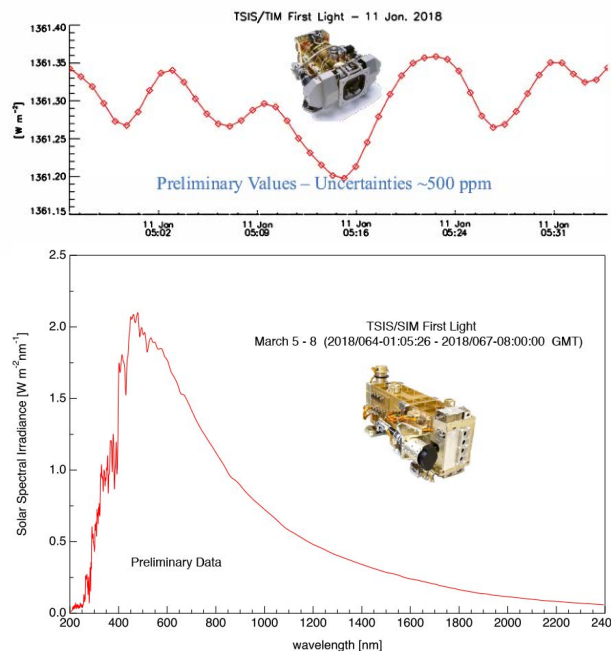
*The Earth Observer* has entered its thirtieth year as a NASA publication. The very first issue was in March 1989. Our archives (<https://eosps.nasa.gov/earth-observer-archive>)<sup>1</sup> are a veritable treasure-trove of history about the development of NASA's Earth Observing System (EOS), the broader NASA Earth Science Research, Applications, and Flight programs, and related education and outreach activities. In the feature article on page 5 of this issue, our Executive Editor (**Alan Ward**) takes us on a trip through *The Earth Observer* archives, no doubt stirring memories in readers who were part of these events. For all our readership, we hope that a better appreciation for the past helps inform our present and future endeavors. The article also allows me the opportunity to publicly thank Alan for his nearly 17 years of service to our newsletter!

Remembering the news of the past has its place, but there is much to report in the present. This is another busy year for Earth Science. On March 1, 2018, GOES-S—the second satellite in the GOES-R series—launched from Cape Canaveral Air Force Station on a United Launch Alliance (ULA) Atlas V rocket, and was renamed GOES-17 by NOAA on March 12 after reaching geostationary orbit. Meanwhile, the first satellite in the GOES-R series, now called GOES-16, launched in November 2016;<sup>2</sup> it now occupies the GOES-East position

<sup>1</sup> Issues as far back as March–April 1999 are archived as pdfs at <https://eosps.nasa.gov/earth-observer-archive>; earlier issues (as of now) are only available as hard copies.

<sup>2</sup> See the Editorial in the November–December 2016 issue of *The Earth Observer* [Volume 28, Issue 6, pp. 1-2] for more details on the payload of the GOES-R series.

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NASA's Total and Spectral Solar Irradiance Sensor-1 (TSIS-1) mission is now in place on the Express Logistics Carrier 3, Site 5, aboard the International Space Station. The photo of TSIS-1 shown here was taken by a camera on the ISS's robotic arm as the Thermal Pointing System (TPS) was moving through its full range of motions. The graphs show "first-light" images from the Total Irradiance Monitor (TIM) obtained January 11, 2018 [top] and from the Spectral Irradiance Monitor (SIM) obtained March 5-8, 2018 [bottom]. **Image credits:** Photo—NASA; TIM data—Greg Kopp [University of Colorado, Boulder, Laboratory for Atmospheric and Space Physics (LASP)]; SIM data—Erik Richard [LASP]

the earth observer

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(having replaced GOES-13 in this position),<sup>3</sup> and has sent back incredible images of powerful hurricanes, major blizzards, and severe thunderstorm outbreaks.<sup>4</sup>

Later this year, after undergoing a full checkout and validation of its six instruments, GOES-17 will operationally replace GOES-15 in the GOES-West position. The new satellite will provide better data than currently available over the northeastern Pacific Ocean, the birthplace of many weather systems that affect the continental U.S. More information is available at <https://www.goes-r.gov>.

Two more launches are scheduled for 2018: the Gravity Recovery and Climate Experiment, Follow-On (GRACE-FO) and Ice, Cloud and land Elevation Satellite-2 (ICESat-2) missions.

GRACE-FO is preparing for launch later this spring—exact date TBD soon—to continue the critical mission began by the U.S./German GRACE mission (2002–2017) of measuring the movements of mass within and between Earth's atmosphere, oceans, land, ice sheets, as well as within the Earth itself due to large earthquakes and very slow changes in Earth's viscous mantle. Following a yearlong test campaign by satellite manufacturer Airbus Defence and Space, the twin satellites were shipped to California's Vandenberg Air

<sup>3</sup>NOAA maintains a two-satellite Geostationary Operational Environmental Satellite (GOES) constellation to watch over the Western Hemisphere. An animation depicting these two positions can be found at <https://svs.gsfc.nasa.gov/4618>.

<sup>4</sup>To learn more about what GOES-R has achieved in its first year, see "GOES-16: The First in a New Generation of Geostationary Satellites" in the November–December 2017 issue of *The Earth Observer* [Volume 29, Issue 6—[https://eosps.nasa.gov/sites/default/files/eo\\_pdfs/Nov\\_Dec\\_2017\\_color\\_508.pdf](https://eosps.nasa.gov/sites/default/files/eo_pdfs/Nov_Dec_2017_color_508.pdf)].

Force Base in December. After being stored for about a month, functional testing of the twin satellites recently resumed. The satellites will next be stacked on a multi-satellite dispenser, which will be used to deploy the twin satellites once they are in orbit. The dispenser will then be moved to the SpaceX facility at Vandenberg in mid-April for integration with the Falcon 9 launch vehicle and final tests. At the SpaceX facility, the dispenser will then be integrated with a second dispenser carrying five Iridium NEXT communications satellites with which the GRACE satellites will share the ride to low-Earth orbit. The combined dispensers and satellites will then be attached to the top of the Falcon 9's upper stage and encapsulated within the Falcon 9's payload fairing for launch.

ICESat-2 is scheduled to launch in September 2018; it will use a laser altimeter to measure snow and ice surfaces on land and the ocean from space. The mission is in the final stages of its environmental testing. Earlier this year, ICESat-2's sole instrument, the Advanced Topographic Laser Altimeter System (ATLAS) was driven from NASA's Goddard Space Flight Center in Maryland to the Orbital ATK facility in Arizona, where engineers joined the instrument with the spacecraft bus. After the integrated ICESat-2 satellite passes further testing, it will be sent to Vandenberg Air Force Base in California to prepare for launch. Meanwhile Operation IceBridge, which was designed to collect ground-based data on sea and land ice thus serving as a "bridge" between the ICESat and ICESat-2 missions, completed a record-breaking year in 2017 with seven field campaigns; the 2018 field season began in mid-March with flights over the Arctic. Turn to page 31 to learn more about a remarkable year for Operation IceBridge.

As reported previously, the Total and Spectral Solar Irradiance Sensor-1 (TSIS-1) was successfully launched to the International Space Station (ISS) on December 15, 2017. Two weeks later TSIS-1 was extracted from the trunk of the SpaceX Dragon capsule and integrated onto its permanent home on Express Logistic Carrier 3. Commissioning began nearly immediately, starting with the TSIS Thermal Pointing System (TPS) that is required to accurately track the Sun and counter the motions and jitter of the ISS—see photo on front page. The TSIS Total Irradiance Monitor (TIM) and Spectral Irradiance Monitor (SIM), the instruments that acquire the total and spectral solar irradiance, respectively, were powered on and vented, then their vacuum doors were opened after allowing for a few weeks of outgassing to avoid internal-instrument contamination. Over 50 individual commissioning activities were successfully completed before solar observations commenced.

The TSIS hardware has thus far performed flawlessly on orbit with preliminary data looking good—see “first light” graphs for TIM and SIM on the cover. Validation and uncertainty determinations will continue over the next several months, but to date all systems are operating within their expected ranges.

Measuring solar irradiance from the ISS presents challenges different than those from dedicated free-flying spacecraft. The ISS structure imposes time-variable obstructions into the instrument fields-of-view that, while anticipated, require accurate detection in order to be flagged in subsequent data processing. The TSIS team is hard at work to avoid these effects, which may manifest in measured signals as either partial occultation or additional solar glint.

In our November–December 2017 issue, we had reported that CloudSat was making preparations to exit the A-Train. These preparations were initiated in June 2017, after one of CloudSat’s reaction wheels displayed significant friction. It was subsequently determined that the wheel would no longer be usable, which was one of the criteria that the CloudSat Project set for exiting the A-Train. While preparations were being made for A-Train exit on three wheels, another reaction wheel began displaying intermittent problems with commanded on/off cycles. Exit burns were developed that use only thrusters (i.e., no reaction wheels), and on February 22, 2018, CloudSat executed two successful thruster-controlled burns, placing the satellite in an orbit below the altitude of the A-Train.

As we reported previously, other A-Train members that use CloudSat radar data for synergistic products and science are keeping close tabs on CloudSat’s plans. In particular, CALIPSO (which launched with CloudSat) is considering an option of leaving the A-Train and joining CloudSat to allow the lidar/radar measurement record to continue. CloudSat is now descending to the

vicinity of the CALIPSO *graveyard orbit*.<sup>5</sup> If CALIPSO chooses to remain in the A-Train, CloudSat will descend to the CloudSat graveyard orbit and resume science operations, once the second reaction wheel problem is overcome.

As reported in our last issue (January–February 2018), based on recommendations from the 2017 Earth Science Senior Review,<sup>6</sup> the Tropospheric Emission Spectrometer (TES) sensor on Aura was decommissioned on January 31.

TES was designed to monitor ozone in the lowest layers of the atmosphere—the first space-based sensor to make such observations. Its high-resolution observations of the troposphere led to new measurements of atmospheric gases that have improved our understanding of the Earth system. Like all the instruments on Aura, TES was planned for a five-year mission—which it far surpassed. A mechanical arm on the instrument began stalling intermittently in 2010, affecting TES’s ability to collect data continuously. The TES operations team adapted by operating the instrument to maximize science operations over time, attempting to extend the dataset as long as possible. However, over time the stalling increased to the point that TES lost operations about half of last year. The data gaps hampered the use of TES data for research, leading to NASA’s decision to decommission the instrument. TES continues to receive enough power to keep warm so that it will not adversely impact the operation of the other Aura instruments. Turn to page 33 to read a News story about the science results that TES achieved during its mission.

Looking toward the future, in early February, NASA Headquarters announced two winning proposals selected from among 14 submitted in response to the Earth Venture Instrument-4 (EVI-4) Announcement of Opportunity.

The Polar Radiant Energy in the Far Infrared Experiment (PREFIRE)—**Tristan L’Ecuyer** [University of Wisconsin, Madison—*Principal Investigator (PI)*]—will fly a pair of small CubeSat satellites (based on technology previously flown on NASA’s Mars Climate Sounder) to probe a little-studied portion of the radiant energy emitted by Earth for clues about Arctic warming, sea ice loss, and ice-sheet melting. The Arctic is one of the most rapidly changing areas on the planet. JPL and the Space Dynamics Laboratory (North Logan, UT) are mission partners.

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<sup>5</sup> It is called a *graveyard orbit* because at this lower orbit atmospheric drag will cause its orbit to slowly erode and reenter Earth’s atmosphere. That should happen about 25 years after it is placed there.

<sup>6</sup> See the Editorial of the January–February 2018 issue of *The Earth Observer* [Volume 30, Issue 1, p. 3] as well as the “Summary of 2017 Earth Science Senior Review Findings” on page 4 of the same issue.

## CloudSat Exits the "A-Train"

Alan Buis, NASA/Jet Propulsion Laboratory, [alan.d.buis@jpl.nasa.gov](mailto:alan.d.buis@jpl.nasa.gov)

**EDITOR'S NOTE:** This article is taken from [nasa.gov](http://nasa.gov). While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

Mission managers at NASA/Jet Propulsion Laboratory (JPL) recently lowered the orbit of the nearly 12-year-old CloudSat satellite following the loss of one of its reaction wheels, which control its orientation in orbit. While CloudSat's science mission will continue, it will no longer fly as part of the Afternoon Constellation, or A-Train—six Earth-monitoring satellites that fly in a coordinated orbit to advance our understanding of how Earth functions as a system.

CloudSat launched in 2006 to improve understanding of the role clouds play in our climate system. It joined the A-Train about a month later. In April 2011, the spacecraft experienced a technical issue affecting the ability of the battery to provide enough current to power all spacecraft systems during the time in each orbit when the spacecraft is on the dark side of the planet and the spacecraft's solar panels are not illuminated. In response, spacecraft engineers at Ball Aerospace developed a new operational mode for CloudSat that enabled it to continue science operations, but only during the part of each orbit when the spacecraft is in sunlight.

Recognizing the vulnerable nature of the spacecraft battery and the age of other spacecraft systems, the CloudSat project developed a set of criteria under which they would exit the A-Train. One criterion was the loss of one of CloudSat's four reaction wheels. Although CloudSat can conduct science operations using only three reaction wheels, a subsequent loss of a second reaction wheel could leave the spacecraft unable to maneuver or change its orientation. Without the capability to maneuver, the satellite could drift too close to another A-Train satellite.

In June 2017, one of CloudSat's reaction wheels displayed significant friction. It was subsequently determined that the wheel would no longer be usable, thus triggering preparations to exit the A-Train.

On February 22, 2018, CloudSat successfully executed two thruster burns, placing the satellite in an orbit below the altitude of the A-Train. After telemetry has been analyzed, mission managers will determine if a third orbit trim burn is necessary. CloudSat will remain in this *safe-exit orbit* while the project studies orbit options for continuing science operations even farther below the A-Train.

CloudSat is the first satellite to use an advanced cloud-profiling radar to "slice" through clouds to see their vertical structure, providing a completely new observational capability from space. The mission furnishes data that evaluate and improve the way clouds and precipitation are represented in global models, contributing to better predictions of clouds and their role in climate change.

Among the mission's many science accomplishments to date, CloudSat has provided the capability to look jointly at clouds and at the precipitation that comes from them, spotlighting flaws in climate model physics: models produce precipitation too frequently, and the



Artist's illustration of NASA's CloudSat satellite, which exited the A-Train on February 22, 2018. **Image credit:** Graeme Stephens [JPL]

modeled precipitation is lighter than actual observations. CloudSat directly quantified, for the first time, global snowfall and found that climate models overestimate Antarctic snowfall, many by more than 100%.<sup>1</sup>

The A-Train satellites rush along together like a train on a "track" 438 mi (705 km) above Earth's surface, flying minutes, and sometimes seconds, behind one another. Together, the satellites and their more than 15 scientific instruments work as a united, powerful tool to examine many different aspects of our home planet. The A-Train

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<sup>1</sup>To learn more about the accomplishments of CloudSat (and its "sister mission" CALIPSO), see "A Useful Pursuit of Shadows: CloudSat and CALIPSO Celebrate Ten Years of Observing Clouds and Aerosols" in the July–August 2016 issue of *The Earth Observer* [Volume 28, Issue 4, pp. 4–15—[https://eospsa.nasa.gov/sites/default/files/eo\\_pdf/July\\_August\\_2016\\_col\\_508.pdf](https://eospsa.nasa.gov/sites/default/files/eo_pdf/July_August_2016_col_508.pdf)].

# A Trip Through Time via the Archives of *The Earth Observer*

Alan B. Ward, NASA's Goddard Space Flight Center/Global Science and Technology Inc., [alan.b.ward@nasa.gov](mailto:alan.b.ward@nasa.gov)

## Introduction

Notably, *The Earth Observer* newsletter is now in its thirtieth year as a NASA publication; our March-April 2019 issue will mark the thirtieth anniversary of the release of the first issue in March 1989. The archives of our publication provide a veritable treasure trove of background information, embodying the written history of NASA's Earth Science program, compiled in real- or near-real time as these events were unfolding. Given this milestone, it is fitting to revisit some highlights from the program's story to date.

For some readers, this may be a trip back to well-remembered events, or jog your memory about what was going on “back then;” for other readers, it is an opportunity to learn some fascinating history that could help inform current and future activities. Specifics may be gleaned by visiting specific issues, as referenced herein.<sup>1</sup>

With that introduction, I invite you now to sit back and travel with me to a time before *Google* became a verb, and an encyclopedia's worth of information on almost any conceivable subject could be at one's fingertips with just a few keystrokes. We will be returning to the era when NASA's Earth Observing System (EOS) Program was just getting started, and there was so much that needed to be communicated to various communities and constituencies.

In an early issue of *The Earth Observer*, Gerald “Jerry” Soffen, the first EOS Project Scientist, quipped: “Our great plan for communications is not yet purring along. A cross-section through the [EOS program] would look like a *Rube Goldberg machine*.”<sup>2</sup> He went on to explain how the project was already “feeling the weight” of the projected terabyte per day of data that was expected to come from EOS missions, long before the actual data started flowing. The fledgling EOS Project Science Office [which had been established at NASA's Goddard Space Flight Center (GSFC) in 1989] was struggling to know what was most important to communicate, and the best means to get the word out. Soffen's words are a reminder that effective communication has been a challenge for EOS from the very beginning. In fact, getting the word out about EOS was a large part of the impetus that led to the creation of *The Earth Observer* about a year earlier.

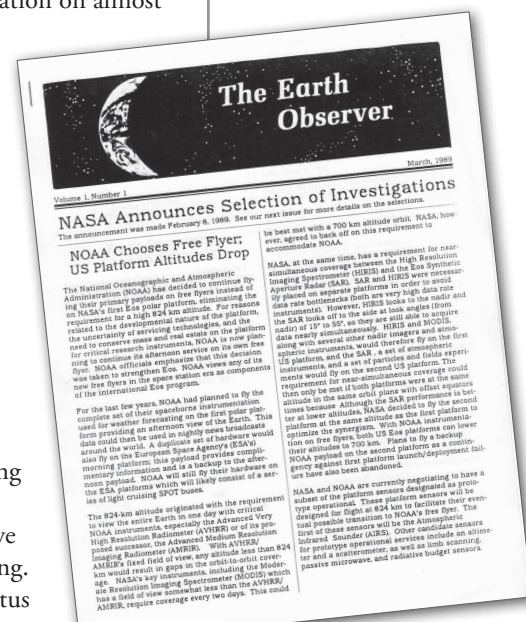
In the years before widespread internet, *The Earth Observer* quickly became a vital communications link between NASA and EOS investigators who were scattered all around the world. It kept them informed about the latest program developments, and scientists could turn to the newsletter for the latest reports from the Investigators Working Group (IWG), payload panels, and instrument science teams, as well as other news from EOS and NASA Earth Science activities.

For our literary journey through the archives, the “Time Interval Dial” (which needs a little calibration, as you'll note) is set to five years, with the “Issue Dial” set to March–April, specifically. Hold on tight, though; time travel is highly unpredictable, especially

<sup>1</sup> Most issues of *The Earth Observer* since March–April 1999 are archived at <https://eosps.nasa.gov/earth-observer-archive>. Issues before 1999 are archived as hard copies but not yet available online.

<sup>2</sup> See “The Editor's Corner” of the January 31, 1990, issue of *The Earth Observer* [Volume 2, Issue 1, p. 1]. Named after the American cartoonist who invented it, a Rube Goldberg machine is a deliberately complex contraption in which a series of devices that perform simple tasks are linked together to produce a domino effect in which activating one device triggers the next device in the sequence, to reach some usually simple goal that would have been easily attained by simpler means.

*For some readers, this may be a trip back to well-remembered events, or jog your memory about what was going on “back then;” for other readers, it is an opportunity to learn some fascinating history that could help inform current and future activities.*



Cover of the first issue of *The Earth Observer* from March 1989. Image credit: NASA

1989

1990

1991

1992

1993



Cover of *The Earth Observer* from March-April 1993.

Image credit: NASA

1990

1999

in those early years before *pdf* files were posted. You never know exactly where we might land nor what memories we might unearth, preserved on the pages of *The Earth Observer*.

### 28 Years Ago

[~March–April 1990, **Volume 2, Issues 2–3**—*Not available online*].

Our machine sputters a bit. It takes tremendous energy to go back to near the very beginning of the story.<sup>3</sup> We emerge at our first stop in 1990—about a year after *The Earth Observer* began. "The Editor's Corner" columns in these two early issues convey the growing sense of excitement as NASA's EOS Project, which began in earnest in 1988 with the selection of the investigators, is now moving from concept toward reality. President George H. W. Bush [1989 - 1993] requested a "New Start" in his 1991 budget request to Congress, and the Office of Technology and Policy (OSTP) issued a plan that called for the establishment of a billion-dollar U.S. Program in Global Change that would include EOS. The U.S. polar platforms envisioned at the time [which included NASA's EOS-A and EOS-B platforms, as well as a National Oceanic and Atmospheric Administration (NOAA) platform] were to be complemented by European and Japanese contributions. At that time, things seemed to be going according to plan—see *The Best Laid Plans—From a Certain Point of View* on page 7.

### 25 Years Ago

[March–April 1993, **Volume 6, Issue 2**—*Not available online*].

We shift our "Year Dial" to 1993, to see if we can get back on our planned five-year interval itinerary. This time the machine works well, and we arrive successfully at our targeted year, where we find that **Michael King** is now the EOS Senior Project Scientist (having replaced **Jeff Dozier** in that role in 1992, who in turn replaced **Jerry Soffen** in 1990). In an effort to help him stay up to date on developments in the rapidly developing EOS Program, King has been appointing scientists to serve as project scientists for each EOS mission. For example, in the previous issue, he had announced several appointments, including **Piers Sellers** to head up AM-1 (which later became known as *Terra*)—see *What's In a Name?* on page 7 to learn more about the original EOS nomenclature.

In the Editor's Corner for this issue, King announces that **Claire Parkinson** has agreed to become PM-1 (later renamed *Aqua*) Project Scientist—a role she still holds today. She replaces **Les Thompson** in this role, who becomes EOS Instrument Scientist. A significant portion of this issue was dedicated to reports from the Geoscience Laser Altimeter (GLAS), Multiangle Imaging Spectroradiometer (MISR), and Moderate Resolution Imaging Spectroradiometer (MODIS) Science Teams. (Although the format of the newsletter has evolved a great deal since the early days, reports from relevant science team meetings and workshops remain a significant part of *The Earth Observer* today, including contributions from some of the same teams that were there at the beginning.)

### 19 Years Ago

[March–April 1999, **Volume 11, Issue 2**—  
[https://eosps.nasa.gov/sites/default/files/ea\\_pdfs/mar\\_apr99.pdf](https://eosps.nasa.gov/sites/default/files/ea_pdfs/mar_apr99.pdf)].

This time, we have overshot our planned five-year time interval by one year, but in this case it is a *clock error* in our favor, as we have landed in a milestone year for the EOS Project.

<sup>3</sup> *The Earth Observer's* "origin story" is told in "The Earth Observer: Twenty-Five Years Telling NASA's Earth Science Story" in the March–April 2014 issue of *The Earth Observer* [Volume 26, Issue 2, pp. 4-13, especially p. 9—[https://eosps.nasa.gov/sites/default/files/ea\\_pdfs/Mar-Apr2014\\_508finalcolor.pdf#page=4](https://eosps.nasa.gov/sites/default/files/ea_pdfs/Mar-Apr2014_508finalcolor.pdf#page=4)].

## The Best Laid Plans—From a Certain Point of View

It has been said that even the best laid plans are subject to change. From our vantage point in 2018, we know such was the case with EOS. One of the late Tom Petty's song lyrics seems applicable: *"Everything changed... then changed again..."*

To put it mildly, EOS concept evolved from what was originally envisioned—although many instruments have actually taken flight in some form. The very earliest plans developed in the pre-*Challenger* era of the 1980s—before *The Earth Observer* existed—called for several platforms that could be serviced from the Space Shuttle, presumably similar to how the Hubble Space Telescope was serviced via the Shuttle. This concept was referred to as "System Z," but it was quickly abandoned. By the time **Jerry Soffen** and **Jeff Dozier** were writing the "Editor's Corner" for *The Earth Observer* in the early 1990s as project scientists, the plan called for two large platforms (EOS-A and EOS-B) each launched on a *Titan IV* rocket, to hold most of the instruments, with perhaps a few smaller supplemental missions, e.g., for ocean color and altimetry.

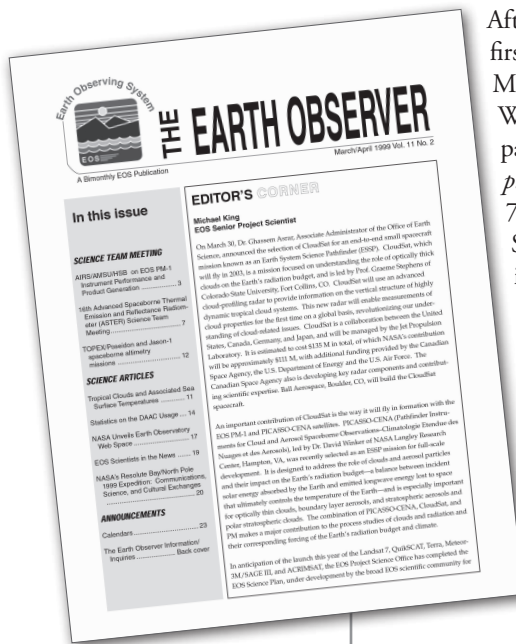
Many of the Editorials written through the mid-to-late-1990s (by **Michael King**) explain how and why the "early 1990s vision" of EOS continued to change, through a series of NASA-directed *revisions*, to become what is in orbit today. What emerged was three midsized "EOS flagship" missions (now known as Terra, Aqua, and Aura) launched on smaller launch vehicles (*Atlas Centaur* for Terra, *Delta II* for Aqua and Aura), supplemented by numerous smaller missions, with contributions from NASA and its international partners.

From 2008–2011, a series of "Perspectives on EOS" articles appeared in *The Earth Observer*. Each author was involved in some aspect of the EOS program in the early days, and some are still active today. All of these articles have been compiled into a single volume available at [https://eosps.nasa.gov/sites/default/files/leo\\_pdfs/Perspectives\\_EOS.pdf](https://eosps.nasa.gov/sites/default/files/leo_pdfs/Perspectives_EOS.pdf). Many of the ideas referenced here are discussed in detail in those articles. In particular, on pages 62–65 of that compendium, **Ghassem Asrar** [former EOS Program Scientist and former Associate Administrator for Earth Science Enterprise at NASA Headquarters] shared his perspective on the evolution of the plans for the EOS flight hardware. His article served as a nice wrap-up to the series, and cross-referenced a number of the previous articles.

## What's in a Name??

The original nomenclature for the EOS satellites represented the local time the satellite would cross the Equator and the number in the series—e.g., AM-1. Early on, scientists (e.g., Piers Sellers) realized the value of having sets of observations at two different times of day. For example, morning observations are particularly helpful to avoid the impact of afternoon cumulus clouds in many locations. This is why Terra (AM-1) has what is called morning, or AM, orbit (–10:30 AM local Equator crossing time) whereas Aqua (PM-1) has an afternoon, or PM orbit (–1:30 PM local Equator crossing time). The number following the dash was in anticipation of each of these satellites being the first in a series of three identical launches over a fifteen-year period to ensure the collection of the long-term, consistent, continuous time-series of key atmospheric parameters needed to study global change.

The third flagship mission, Aura, was originally called CHEM-1, and has an afternoon local equator crossing time—lagging a few minutes behind Aqua, but close enough to allow intercomparison between instruments on each platform. Although there are occasional references to the proposed series of AM and PM missions in old Editorials in *The Earth Observer*, the envisioned "follow-on" launches were eventually eliminated, and the plan revised. Driven somewhat out of necessity, the famous (or infamous) "mother of invention," NASA scientists and engineers came up with more flexible—and less expensive—alternative mission concepts to obtain the continuous observations they desired—e.g., constellation-flying concepts, such as has developed with the implementation of the A-Train, could obtain the same results as having repeated flights of the same instruments on a single large or midsized platform, with less risk and lower cost. See pages 62–65 of the "Perspectives on EOS" compendium referenced earlier to learn more about the evolution of the EOS concept.



Cover of *The Earth Observer* from March-April 1999.  
Image credit: NASA

After nearly a decade of development, and several launch delays the first EOS missions are finally ready to take flight! The Tropical Rainfall Measuring Mission (TRMM) and Orbview-2 [with NASA's Sea-viewing Wide Field-of-view Sensor (SeaWiFS) onboard] missions, both considered part of EOS, have been in orbit since 1997, but 1999 has five launches *planned* for this year. In addition to Terra—the EOS “flagship”—Landsat 7, the Quick Scatterometer (QuikSCAT), the Active Cavity Radiometer Satellite (ACRIMSAT), and the Russian Meteor-3M mission, which included the Stratospheric Aerosol and Gas Experiment III (SAGE III), are all preparing for launch. (All but one of these launched in 1999; Meteor-3M/SAGE III was delayed until 2001.)

The Editor's Corner in this issue announced the selection of CloudSat as the fourth Earth System Science Pathfinder mission.<sup>4</sup> The same Editorial also mentions publication of the *EOS Science Plan*, which was released as EOS observations were beginning in earnest, and presented a comprehensive overview of all aspects of EOS science.

An article in this issue reports on an event that was—at the time—a communications milestone. A group consisting of NASA engineers, scientists, and outreach personnel traveled to Resolute Bay and Eureka, Canada, and from there to “the top of world,” where they conducted the first-ever Internet webcam from the North Pole.

Another item in this issue, which we now view as a communications milestone for Earth Science, announced the debut of *The Earth Observatory* website (<https://earthobservatory.nasa.gov>). The article stated that the site was established to “...help improve communications between Earth scientists and the general public, presenting the compelling stories of Earth science in ways the public could easily understand, and help them learn about global climatic and environmental change.” Nearly two decades later, the site has grown considerably from its humble origins, and is still going strong, doing what it set out to do. This longevity and growth are tributes to the many people who have worked to produce its informative content over the years as well as its popularity with the interested public.

One final note before moving on with our journey, the March-April 1999 issue is the earliest saved online as a *pdf* file—something now done as standard practice.

### 15 Years Ago

[March–April 2003, **Volume 15, Issue 2**—  
[https://eosps.nasa.gov/sites/default/files/eo\\_pdfs/mar\\_apr03.pdf](https://eosps.nasa.gov/sites/default/files/eo_pdfs/mar_apr03.pdf)].

Having come to grips with our flakey Time Interval Dial, we stick the landing on our next stop, in 2003. The big news at this time is the successful January launch of both the Solar Radiation and Climate Experiment (SORCE) and Ice, Clouds, and land Elevation Satellite (ICESat). ICESat carried the Geoscience Laser Altimeter (GLAS), which had been part of the EOS plan from early on. Meanwhile, SORCE combined two earlier conceived EOS missions: the Solar Stellar Irradiance Comparison Experiment (SOLSTICE) and Total Solar Irradiance Mission (TSIM). The Editorial also mentioned the release of a revised version of Volume One of the *EOS Data Products Handbook* (DPH)—see *What in the Wild World of EOS Was a Data Products Handbook?* on page 9 to learn more.

<sup>4</sup> Previous ESSP selections included the Gravity Recovery and Climate Experiment (GRACE), Vegetation Canopy Lidar (VCL) (which never flew), and PICASSO-CENA (later renamed the Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations, or CALIPSO) missions. CloudSat and CALIPSO were launched together in 2006; both were part of the Afternoon Constellation, or A-Train (<https://atrain.gsfc.nasa.gov>). CloudSat exited the A-Train on February 22, 2018—see story on page 4 for details.

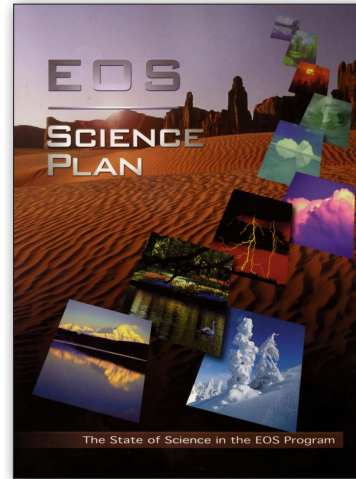


## What in the Wide World of EOS Was a Data Products Handbook?

Quality print publications have always been a hallmark of the Science Communications Support Office (SCSO),<sup>1</sup> located at GSFC, which produces *The Earth Observer*. In the early days, before similar information was easily accessible online, such products were an important complement to the newsletter, helping to get information about EOS into the hands of the investigators that needed it. In addition to many fact sheets, lithographs about a variety of Earth science topics, and brochures for the missions and instruments as they prepared to launch, the EOS Project Science Office (as the SCSO was known until 2015) produced an *EOS Science Plan* (described on page 8), a two-volume *Data Products Handbook* (DPH), plus an *EOS* (later restructured into a broader *Earth Science*) *Reference Handbook*—last updated in 2006.

The two DPHs contained meticulously detailed summaries of the many planned data products for the EOS program of record. Each successive release of the *Reference Handbook* contained information on various program elements of the Earth Science Program as it existed at the time, including summaries of each planned mission, with detailed descriptions of instruments, and abridged data product lists. In later years, CD-ROMS were produced, eliminating the need to use the huge amounts of paper needed to print bulky books. As time went on, most of the information in these comprehensive compendia became readily available online. However, no doubt some devotees (including the author) still have old, dusty, dog-eared copies of these three tomes on their shelves and may yet still refer to them on occasion.

<sup>1</sup>The SCSO is the primary point of contact for NASA's Science Mission Directorate and Earth Science Division for science exhibit outreach and product development. Learn much more about the SCSO in "NASA's Science Communications Support Office 2017 Annual Report" available at [https://eospsa.nasa.gov/sites/default/files/publications/AnnualReport2017\\_508-v2.pdf](https://eospsa.nasa.gov/sites/default/files/publications/AnnualReport2017_508-v2.pdf).

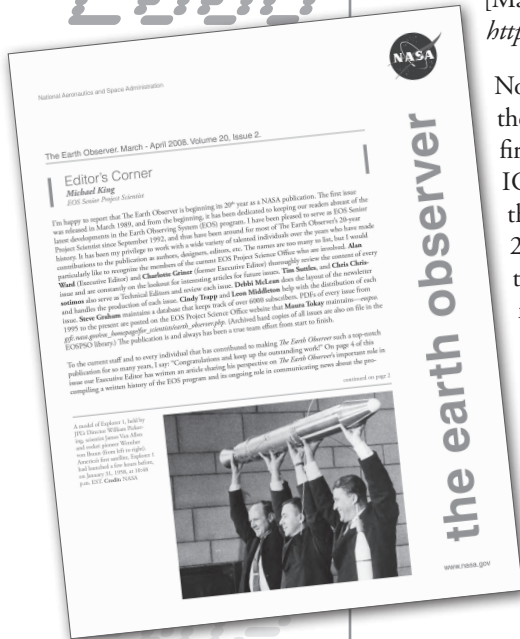


The cover of the EOS Science Plan: *The State of Science in the EOS Program*, published in 1999 after more than four years of development. **Image credit:** NASA



The cover of the EOS/Earth Science Reference Handbook as it evolved through time from 1990–2006. **Image credit:** NASA

2008



Cover of *The Earth Observer* from March-April 2008.  
Image credit: NASA

2013



Cover of *The Earth Observer* from March-April 2013.  
Image credit: NASA

2018

2019

10 Years Ago

[March–April 2008, **Volume 20, Issue 2**—  
[https://eosps.nasa.gov/sites/default/files/eo\\_pdfs/Mar\\_Apr08.pdf](https://eosps.nasa.gov/sites/default/files/eo_pdfs/Mar_Apr08.pdf)].

Now we move smoothly forward to 2008. It is not long after the release of the National Research Council's 2007 Earth Science Decadal Survey—the first ever for Earth Science.<sup>5</sup> The Soil Moisture Active/Passive (SMAP) and ICESat-2 missions were *Tier 1* priorities in that plan, and they are among the items that received funding in President Barack Obama's [2009–2017] 2009 budget request. As it often does in March–April timeframe, the Editor's Corner reported on the budget's details. The editorial also mentioned that the future role and scope of the EOS Project Science Office was being evaluated in light of the Decadal Survey recommendations. Meanwhile, after 30 years of service to NASA—and fifteen-and-a-half years as EOS Senior Project Scientist—Michael King retires. He announces that **Steve Platnick**, who had formerly been Deputy Project Scientist for Aqua, will be his replacement on an *Acting* basis. (The role would later become permanent, and Platnick remains EOS Senior Project Scientist to this day.)

This issue featured an article on *The Earth Observer* itself as it began its twentieth volume, in which the executive editor (and author of this current article, still in the role of executive editor) shared his views on the publication. The article became the launching point for the series of *Perspectives on EOS* articles—mentioned in *The Best Laid Plans—From a Certain Point of View* on page 7—that followed over the next several years.

5 Years Ago

[March–April 2013, **Volume 25, Issue 2**—  
[https://eosps.nasa.gov/sites/default/files/eo\\_pdfs/March\\_April\\_2013\\_508\\_color.pdf](https://eosps.nasa.gov/sites/default/files/eo_pdfs/March_April_2013_508_color.pdf)].

Our final scheduled stop of the journey is upon us. Immediately we notice a difference; the online *pdf* file is produced in vibrant color—a practice which began in 2011. The Editorial from this issue highlights the launch of the Landsat Data Continuity Mission, (LDCM; now known as Landsat 8), and the issue contains a full article that gives an overview of the mission. Another article reported on a recently selected Earth Venture mission<sup>6</sup> known as the Tropospheric Emissions: Monitoring of Pollution (TEMPO) mission, which will make air pollution measurement over a large section of North and Central America from geostationary orbit.

Conclusion

Having completed our journey, we're now back to the present, none the worse for wear for our journey, and potentially having gained significant benefit from it. Hopefully what we learn about the past can train us for the future.

<sup>5</sup> The 2007 Earth Science Decadal Survey is available at <https://www.nap.edu/catalog/11820/earth-science-and-applications-from-space-national-imperatives-for-the>. A second Earth Science Decadal Survey was completed in 2017, and can be downloaded from <https://www.nap.edu/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth>.

<sup>6</sup> Earth Venture Class missions were another innovation that came from the recommendations of the 2007 Earth Science Decadal Survey, calling for development of low-cost, principal investigator (PI)-led, competed orbital and suborbital missions that are built, tested, and launched in short time intervals. Learn more about these missions at <https://essp.nasa.gov/projects>.

Clearly we see that from its inception, *The Earth Observer* has been a vital cog in getting the word out about NASA Earth Science. Though the specifics have changed considerably in 30 years, the newsletter continues in that same role today. While up-to-the-minute information is much more readily—and rapidly—available from other sources today, the newsletter continues to fill a vital Earth Science communications niche as a unique print publication. Then as now, we focus on reporting the Earth Science news of the present—and plans for the future. As was the case with its predecessor in 2007, the recently released 2017 Earth Science Decadal Survey and the ever-changing political and financial landscapes are sure to generate challenges and opportunities for NASA's Earth Science program. *The Earth Observer* remains committed to bringing the stories of NASA Earth Science to a broad community of readers.

On behalf of the staff of *The Earth Observer*, thank you for your loyal support over nearly three decades; we look forward to your continuing support for our efforts to keep you engaged, involved, and informed. ■

*Clearly we see that from its inception, **The Earth Observer** has been a vital cog in getting the word out about NASA Earth Science. Though the specifics have changed considerably in 30 years, the newsletter continues in that same role today.*

## Editor's Corner

*continued from page 4*

The Earth Surface Mineral Dust Source Investigation (EMIT)—**Robert Green** [JPL—PI]—will fly a hyperspectral sensor based in part on NASA's Moon Mineralogy Mapper instrument aboard the Indian Space Research Organization's Chandrayaan-1 spacecraft. Following the lead set by other upcoming EVI missions (e.g., GEDI and ECOSTRESS), the EMIT instrument will be mounted to the exterior of the International Space Station to determine the mineral composition of natural sources that produce dust aerosols around the world. The composition of such mineral dust is not well known at present, making it difficult to quantify the radiative properties of this aerosol type.

To learn more about these two new Venture Class NASA Earth Science missions,<sup>7</sup> see <https://www.nasa.gov>.

<sup>7</sup> The National Research Council's (NRC) *2007 Earth Science Decadal Survey* recommended in 2007 that NASA undertake this type of regularly solicited, science-based, quick-turnaround project. The NRC's newly released *2017 Earth Science Decadal Survey* recommended the continuance of the program. Learn more about the various types of Venture Class missions at <https://essp.nasa.gov>.

[gov/press-release/new-nasa-space-sensors-to-address-key-earth-science-questions](https://www.nasa.gov/press-release/new-nasa-space-sensors-to-address-key-earth-science-questions).

The story of NASA Earth Science continues to be chronicled in each successive volume of *The Earth Observer*. While there have been, and will always will be, inevitable plot twists as new strategies are implemented in response to changing political and economic environments, NASA will continue to make innovative use of technology to learn more about the world we call home. Communication has certainly changed a great deal in the nearly three decades this publication has existed and *The Earth Observer* has evolved in response (reminder that a full color PDF version is available online, as well as the option to "Go Green" and opt out of receiving a print copy). But our commitment to telling NASA's Earth Science story to you, our readers, remains steadfast. On behalf of the entire staff, we thank you for your interest and support over these many years. ■

### Undefined Acronyms Used in Editorial and Table of Contents

CALIPSO	Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations
ECOSTRESS	ECOSystem Spaceborne Thermal Radiometer Experiment on Space Station
GEDI	Global Ecosystem Dynamics Investigation
GOES	Geostationary Operational Environmental Satellite
IABG	Industrieanlagen-Betriebsgesellschaft GmbH* [German]
JPL	NASA/Jet Propulsion Laboratory
NOAA	National Oceanic and Atmospheric Administration

\* GmbH stands for Gesellschaft mit beschränkter Haftung, which is essentially the German equivalent of a limited liability company (LLC) in the U.S.

## Overview of 2017 NASA Sounder Science Community Activities

Eric J. Fetzer, NASA/Jet Propulsion Laboratory, California Institute of Technology, [eric.j.fetzer@jpl.nasa.gov](mailto:eric.j.fetzer@jpl.nasa.gov)

### Introduction

Two meetings of NASA's atmospheric sounder community took place during 2017. The Atmospheric Infrared Sounder (AIRS) Science Team met April 17-18 at the Beckman Institute at the California Institute of Technology in Pasadena, CA. It focused on long-term science resulting from AIRS measurements and synergies between AIRS and other sounders. Later in the year, NASA's Sounder Science Team Meeting (STM), was held October 24-26 in Greenbelt, MD. It showcased a broad range of analyses of sounder data by NASA researchers and by colleagues from around the world. The AIRS Project at the NASA/Jet Propulsion Laboratory (JPL) hosted both of these meetings.

For context, the article begins with a short review of the development of sounding instruments and their contribution to NASA Earth Science research, and then the two meetings will be summarized individually. For more details, including presentations from the Sounder STM, visit <https://airs.jpl.nasa.gov/resources/presentations>.

### Review of Atmospheric Sounding Instruments and Their Contributions to NASA Earth Science

The remote observation of atmospheric vertical structure, or *sounding*, by satellite-borne instruments is an important component of NASA Earth Science activities. NASA sounder science involves a variety of satellite instruments, with high-resolution infrared (hyperspectral IR) being the most data-rich; six hyperspectral IR instruments have been launched since 2002 by NASA and other organizations. Most hyperspectral IR instruments are still functioning, and others are planned for the coming decades. These instruments have associated science teams, and coordination between those teams is active and ongoing. Those instruments, the teams, and sounder science activities during 2017 are described here.

The sounder record includes directly observed radiances and also the geophysical state quantities like temperature and water vapor retrieved from those radiances. Additional sounder observations include retrieved cloud properties and the distribution of a variety of trace gases. Sounder observations primarily come from hyperspectral IR sounders (which are described in the text that follows) and from the dozen or so related microwave and coarse spectral-resolution IR sounders. Sounder datasets are produced by three NASA supported teams (listed later) but are freely available and being analyzed by a broad community of domestic and international researchers.

The foundation of the sounder effort is a set of passive instruments observing at infrared and microwave frequencies, with greatest spectral information coming from the troposphere. While atmospheric sounders have been in orbit starting with the Nimbus satellite series in the 1970s,<sup>1</sup> they saw a significant advance in capability in 2002, with the launch of the hyperspectral Atmospheric Infrared Sounder (AIRS) on the Aqua spacecraft. AIRS spatial sampling is comparable to earlier infrared instruments, observing more than 300,000, 50-km-wide (~31-mi-wide) fields-of-view per day. However, AIRS includes nearly three thousand spectral channels—which is about two orders of magnitude more than earlier instruments—and each field-of-view includes nine distinct infrared spectra, for a total of about 2.9 million high-resolution spectra per day—i.e., more than 30 per second!

The AIRS instrument is co-aligned with two other instruments: the Advanced Microwave Sounding Unit-A (AMSU-A), and the microwave Humidity Sounder for Brazil (HSB); unfortunately, HSB stopped operating in February 2003 after only a few months in orbit. AMSU-A has also been slowly losing capability since 2010, but the AIRS instrument is still in nominal operation almost 16 years after launch. Retrieval algorithms convert radiances from AIRS/AMSU into geophysical quantities. The AIRS/AMSU record of observed radiances and retrieved geophysical fields provides a wealth of information about atmospheric phenomena: The fundamental measurement goal of AIRS was improved information about temperature and water vapor, a goal common to most of the instruments described here. The creation and interpretation of the AIRS/AMSU datasets are ongoing. NASA established the AIRS Science Team to oversee the activities of these three instruments.

Meanwhile, the payload of NASA's Aura satellite, launched in 2004, also included an infrared sounder: the Tropospheric Emission Sounder (TES). Aura launched into the same orbit as Aqua, crossing the equator a few minutes later, in a formation that was later joined by four other NASA and international satellites, known as the Afternoon Constellation, or "A-Train."<sup>2</sup> TES observed a wide variety of trace gas spectral signatures, a capability enabled by finer spectral resolution and

<sup>1</sup>To learn more about the Nimbus series, see "Nimbus Celebrates 50 Years" in the March–April 2015 issue of *The Earth Observer* [Volume 27, Issue 2, pp. 18–31—[https://eosps.nasa.gov/sites/default/files/leo\\_pdf/Mar\\_Apr\\_2015\\_color\\_508.pdf](https://eosps.nasa.gov/sites/default/files/leo_pdf/Mar_Apr_2015_color_508.pdf)].

<sup>2</sup>To learn more about the A-Train, visit <https://atrain.gsfc.nasa.gov>.

more complete spectral coverage than AIRS, although with roughly two orders of magnitude sparser spatial sampling. Unlike AIRS/AMSU on Aqua, TES did not fly with a companion microwave instrument that measured in the same altitude range.<sup>3</sup> NASA's TES Science Team was set up to oversee the operation of TES, which was decommissioned in January 2018. The science team will continue to oversee the creation of a long-term record of atmospheric composition.

The next sounding instruments were European contributions, part of the payload of the European Organisation for the Exploitation of Meteorological Satellite's (EUMETSAT) first Operational Meteorology satellite, called Metop-A, launched in 2006. They included the Infrared Atmospheric Sounding Interferometer (IASI), along with another AMSU-A and the Microwave Humidity Sounder (MHS). MHS is similar to the short-lived HSB on Aqua and similarly with the AIRS/HSB combination on Aqua, AMSU-A and MHS are co-aligned with IASI on the MetOp satellites. While NASA does not have a science team charged with creation and analysis of IASI/AMSU/MHS data, those data have been used in several NASA-supported studies, and representatives of these instruments frequently present results at AIRS and Sounder STMs.

The next NASA-contributed sounders came in 2011, when NASA launched the Suomi National Polar-orbiting Partnership (NPP) platform. Its payload included the Cross-track Infrared Sounder (CrIS) and companion Advanced Technology Microwave Sounding Suite (ATMS), with combined capabilities of AMSU-A and MHS. Suomi NPP is now operated by the National Oceanic and Atmospheric Administration (NOAA) and is an operational weather-observing platform. Development of a long-term sounder record using the instruments on Suomi NPP is an important part of NASA's sounder activities, and NASA created a Suomi NPP Sounder Science Team to oversee this effort.

Because of the significant positive impact of sounder observations on weather forecasting, the international community is committed to a continuing record. A second IASI/AMSU/MHS instrument suite launched on Metop B in September 2012,<sup>4</sup> and a second CrIS/ATMS suite was launched on the Joint Polar-orbiting Satellite System-1 spacecraft in 2017 (JPSS-1; now known as NOAA-20). Thus, the modern sounder record now includes observations from six infrared instruments (AIRS, TES, two IASI, and two CrIS), and several associated microwave instruments. All the infrared instruments except TES are still operating, and their records

include observational overlaps ranging from months to longer than a decade. Microwave instruments are also an important part of the sounder record, especially data from instruments with increased sensitivity to water vapor (e.g., MHS) launched after 2000. Furthermore, the record is supplemented by a number of lower-resolution infrared Television Infrared Observational Satellite (TIROS) Operational Vertical Sounder [TOVS] sensors that have been flying since the 1970s, including those flying on the Metop-A and -B platforms carrying IASI. Emphasizing the importance of these instruments and their data, both NASA and EUMETSAT have committed to supporting one or more hyperspectral infrared-microwave sounder suites into the 2030s.

The interpretation of sounder datasets brings many scientific challenges, ranging from establishment of the validity of individual measurements, to interpretation of large records of complex global phenomena, to the grand challenge of creation of a combined record from all the sounders. This challenge is being met by the entire NASA (and international) sounder science community, resulting in extensive coordination between the different instrument teams described herein. As a consequence, the boundaries between the AIRS and Sounder STMs in the summaries that follow are somewhat arbitrary—and somewhat porous. As regards the STMs, 2017 was typical for the sounder community, with the AIRS STM taking place in the spring, and the Sounder STM taking place in the fall. (The TES Science Team meets independently of these two groups, but again, there is overlap.) These meetings are discussed below.

### The NASA AIRS Science Team Meeting

The AIRS STM was held immediately prior to the NASA A-Train Symposium, which took place April 19–21, 2017, in the same location.<sup>5</sup> The theme of the AIRS Science Team Meeting was expressed in the question posed by **Joao Teixeira** [JPL—AIRS Science Team Leader] during the Introduction: *Which science questions are essential to address with the 40-year record of infrared (IR) sounder observations that are currently available and planned for the future?* This question implicitly expands the discussion beyond AIRS, to include the list of instruments described in the Introduction of this article.

The remainder of the meeting was then spent attempting to formulate the Science Team's answers to this question. There were a series of eight, 45-minute invited presentations, each of which involved some aspect of using satellite observations from sounders or satellite observations

<sup>3</sup> Aura does have the Microwave Limb Sounder (MLS) instrument onboard. However, TES and MLS were not designed to observe in tandem, as is the case of the other sounder suites described here.

<sup>4</sup> Metop-C is scheduled to launch later in 2018, and will have the same instruments as its predecessors.

<sup>5</sup> To learn more about this meeting, see “The Third A-Train Symposium: Summary and Perspectives on a Decade of Constellation-Based Earth Observations” in the July–August 2015 issue of *The Earth Observer* [Volume 29, Issue 4, pp. 4–18—[https://eosps.nasa.gov/sites/default/files/ea\\_pdf/July%20August%202017%20color%20508.pdf](https://eosps.nasa.gov/sites/default/files/ea_pdf/July%20August%202017%20color%20508.pdf)].

**Table.** List of invited speakers at the 2017 AIRS STM, their affiliations, and presentation titles.

Speaker	Affiliation	Presentation Title
<b>Larrabee Strow</b>	University of Maryland, Baltimore County	Long-Term Science Questions for Hyperspectral Sounders: New Practical (?) Approaches
<b>Norman Loeb</b>	NASA's Langley Research Center (LaRC)	Tracking Changes in Earth's Energy Budget: The Need for Multiple Independent Observations
<b>Jack Kaye</b>	NASA Headquarters	NASA Headquarters Perspective
<b>Graeme Stephens</b>	NASA/Jet Propulsion Laboratory (JPL)	Atmospheric Sounding and Profiling: A Look Ahead
<b>Nathaniel Livesey and Michelle Santee</b>	Both at JPL	Capitalizing on a Multi-Decadal Record of Atmospheric Composition Observations from the Upper Troposphere to the Mesosphere
<b>Vivienne Payne</b>	JPL	The Value of Long-Term Composition Records for Chemistry, Air Quality, and Climate Research
<b>Xianglei Huang</b>	University of Michigan	The Spectral Dimension of Climate Studies: Trend Detection, Model Evaluation, and Feedback Analysis
<b>Brian Soden</b>	University of Miami	Water Vapor Trends

from nonsounder instruments with multidecadal records. The speakers represented a wide range of backgrounds and answered the question from their own unique perspectives. The Table above lists all the invited speakers, their affiliations, and their presentation titles.

In addition to the invited presentations, there were two, 90-minute discussion sessions, which attempted to answer the theme question in the context of the topics Atmospheric Composition (led by **Vivienne Payne** [JPL] of the TES Science Team), and Atmospheric Physics (led by **Eric Fetzer** [JPL] of the AIRS Science Team). Summary and plenary discussions rounded out the agenda.

A synthesis of the answers to the question posed at the start of the meeting can be summarized in two parts—and supported by presentations described in the next section, made during the more-extensive three-day Sounder STM.

The first requirement to establish a scientifically rigorous multidecadal record is to undergird it with a set of well-calibrated and cross-calibrated radiances from multiple instruments. This requirement is well on its way to being met with instruments presently in orbit—e.g., see presentations by **Henry Revercomb** and **Larrabee Strow** summarized later in the Sounder STM Summary. The second requirement for a multidecadal record is having a consistent set of retrieved geophysical quantities derived from the observed radiances. Most scientific analyses of sounder observations are performed on retrieved quantities. The challenge of creating a consistent record of retrieved quantities is also being addressed at this time, though much work remains to be completed—e.g., see presentation

by **Christopher Barnet**, also summarized later in the Sounder STM Summary.

### The NASA Sounder Science Team Meeting

This comprehensive meeting included a larger set of participants than the AIRS science team meeting. To coordinate the 60, 20-minute talks over three full days, the meeting was organized into the following sessions:

- Introduction;
- Weather and Climate;
- Atmospheric Composition;
- Applications and Products;
- Retrieval Methods;
- Validation; and
- Calibration.

What follows are some highlights from the meeting. The presentations chosen for this summary were the ones the Science Team deemed to address themes most relevant to NASA sounder science: the interpretation of the long-term sounder record; the combining of observations from different sounder instruments; the use of sounder observations to study new or important phenomena; and, the interpretation of sounder observations in the context of model simulations and other satellite observations. This resulted in eight presentations from the meeting being summarized here; most of the 60 presentations from that meeting are available at the AIRS Science Team website provided earlier.

**Henry Revercomb** [University of Wisconsin] described the calibration characteristics of CrIS. He noted that the CrIS performance is comparable to—and in some ways better than—AIRS. Revercomb also showed that radiance trends from AIRS, CrIS, and the two IASI instruments are very similar. This means that the hyperspectral IR record begun with AIRS can be extended with the radiances from these other instruments—a basic requirement for a multidecadal record as noted during the AIRS STM.

**Dennis Hartmann** [University of Washington] showed consensus results from a group of 11 climate models. The model projections show that low cloud cover will decrease at the rate of about 1% per K of warming. This is a net positive feedback on warming because low clouds reflect sunlight, so reduced low cloud cover means increased surface solar heating. Hartmann used low cloud properties from the Moderate Resolution Imaging Spectroradiometer (MODIS) flying on Aqua, along with temperature and atmospheric water vapor profiles from AIRS, to show that simulated processes in the climate models are consistent with observed physical processes. This bolsters conclusions about projections of low cloud cover by those models.

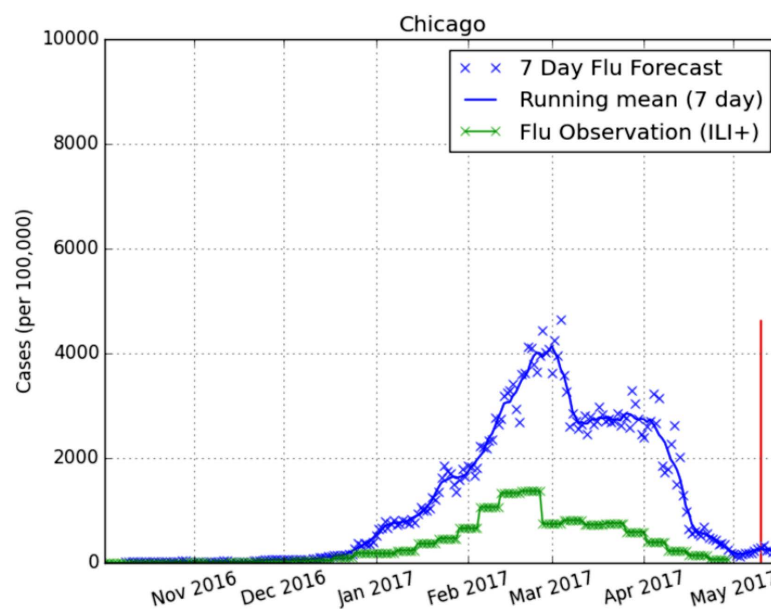
**Stephen Leroy** [Atmospheric and Environmental Research (AER)] used a combination of climate models and AIRS and Global Positioning System–Radio Occultation (GPS-RO) retrievals to look for changes in air temperature that have occurred since the launch of Aqua in 2002. AIRS and GPS-RO data indicate consistent warming on the order of 0.05 K per year in the upper troposphere and in the subtropical belts, indicating a widening of the tropical *Hadley cells* (the result of upward motion in thunderstorms near the equator and downward motion in the subtropics). This result is consistent with results from several other studies using a variety of observational and model reanalysis datasets.

In the latest series of studies looking at surface flux quantities in the Arctic, **Linette Boisvert** [NASA's Goddard Space Flight Center/ University of Maryland, Baltimore County (UMBC)] examined moisture flux from the Greenland Ice Sheet estimated from AIRS temperature and water vapor observations. She compared the fluxes to those from the Regional Atmospheric Climate Model version 2.3. For cold, frozen surfaces the moisture flux into the atmosphere occurs by sublimation from ice directly into water vapor, while

evaporation from wet snow becomes important for dew point temperatures above freezing. Boisvert showed that while these processes only represent 5-10% of total annual mass balance of Greenland, they can become the dominant loss process during the warmest months and at lowest elevations.

**Karen Cady-Pereira** [AER] showed results from an analysis of TES observations of air pollution over 17 megacities. TES had higher spectral resolution than other hyperspectral IR sounders, so it could observe a wider variety of gases, although at coarser spatial resolution. The gases in this study included ozone, ammonia, methanol, and formic acid. She also examined carbon monoxide, MODIS aerosol optical depth, aerosol optical depth and sulfur dioxide profiles from the Ozone Mapping and Profile Suite (OMPS) on Suomi NPP, and ammonia profiles from CrIS. Cady-Pereira was able to connect pollution events over megacities to local pollution production and weather conditions, and to distant biomass burning and wind transport.

**Heidar Thrastarson** [JPL] examined AIRS data for precursor meteorological conditions leading to disease outbreaks. He showed that increased incidence of influenza over the U.S. was preceded by periods of low specific humidity as observed by AIRS. (The influenza-humidity relationship was known prior to the study.) Thrastarson was able to retroactively forecast influenza frequency in U.S. cities with a lead time of about seven days and is working to develop an operational influenza forecast system (see **Figure**). Similarly, he was also able to show that an observed increase in dengue fever cases in Mexico was preceded for several weeks by periods of increased temperature and humidity as observed



**Figure.** Influenza cases in Chicago, IL per 100,000 residents, and forecast of cases based on AIRS near-surface relative humidity and a theoretical relationship between observed cases and humidity. The forecast curve captures the shape of the observational curve, but not its magnitude because of limited understanding of influenza transmission. **Image credit:** Heidar Thrastarson [JPL]

by AIRS. This finding is consistent with what would be expected, since warm, moist conditions favor the growth and reproduction of the mosquito species (*Aedes aegypti*) that transmits dengue fever.

**Christopher Barnet** [Science and Technology Corporation] described an algorithm to use radiance inputs from the five currently operating hyperspectral IR-microwave sounder suites described earlier to retrieve geophysical state variables such as temperature and water vapor. This algorithm uses the Modern-Era Retrospective analysis for Research and Applications (MERRA) reanalysis results as input. Therefore, any further derived results are a retrieved perturbation to an initial state that embodies model physics and includes information from a large variety of assimilation data sources (including sounders). The retrieval algorithm also uses a detailed surface IR emissivity model developed with observations from a variety of satellite instruments.

**Larrabee Strow** [UMBC] described a comparison of radiances from AIRS on Aqua and CrIS on Suomi NPP during simultaneous nadir overpasses, when both instruments view downward within 20 km (~12 mi) and 20 minutes of each other. Because the viewing conditions are nearly identical for both instruments, a detailed comparison of radiances was possible. Strow showed that both instruments were stable during the five years of his study, with trends that agree to within 0.001 K in brightness temperature in all channels. This agreement is within the radiometric uncertainties of both instruments.

## Conclusion

During a day-and-a-half in April 2017, the AIRS STM addressed current and future challenges of creating and maintaining the multidecadal sounder record. The presentations and discussion showed that the radiance portion of the long-term multisensor sounder record is consistent within the range of measurement noise, but reconciling the subsequent retrieved quantities from sounders on different spacecraft remains a challenge.

Speakers at the three-day NASA Sounder STM in October demonstrated the breadth and maturity of the science based on the modern sounder record. They clearly showed that the modern hyperspectral IR sounder radiance record is consistent between sensors on different satellites. They also showed that sounder observations have been critical in improving weather forecasts, thus ensuring their future continuity. Such results are also proving to be a valuable record of climate and climate processes, and the AIRS record of nearly 16 years provides clear evidence of climate change, particularly in the Arctic. The sounder record (especially from IASI and CrIS, with more spectral coverage than AIRS) also shows changes in trace gases and pollutants. Sounder observations can be interpreted in the context of other satellite observations, and also the context of weather and climate model simulations.

Future sounder science teams will share recent results and continue to address the grand challenge of creating a unified record from the many current and future satellite sounding instruments. These and other topics will be on the agenda of the next AIRS STM, to be held April 25-27, 2018, in Pasadena, CA. ■

## CloudSat Exits the "A-Train"

*continued from page 4*

has proven to be a successful integrated approach to observing Earth because it allows multiple instruments to observe the same location on Earth nearly simultaneously as they pass overhead. In addition to CloudSat (a partnership with the Canadian Space Agency and the U.S. Air Force), the other satellites currently in the A-Train include NASA's Aqua, Orbiting Carbon Observatory-2, and Aura spacecraft; the NASA/Centre National d'études Spatiales (CNES) Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO) spacecraft; and the Japan Aerospace Exploration Agency's Global Change Observation Mission - Water (GCOM-W1) satellite.

With CloudSat now in an orbit below the A-Train, it will occasionally pass beneath the constellation, enabling the mission to collect data in support of some of its pre-A-Train-exit data products.

For information on CloudSat and the A-Train, visit:

<http://www.nasa.gov/CloudSat>

<http://CloudSat.atmos.colostate.edu>

<https://atrain.nasa.gov>. ■



# Summary of the Fourth GEDI Science Definition Team Meeting

*Suzanne Marselis, University of Maryland, College Park, marselis@umd.edu*

*John Armston, University of Maryland, College Park, armston@umd.edu*

*Ralph Dubayah, University of Maryland, College Park, dubayah@umd.edu*

## Introduction

The Fourth Global Ecosystem Dynamics Investigation (GEDI) Science Definition Team (SDT) meeting was held at the NASA Goddard Visitor Center at NASA's Goddard Space Flight Center (GSFC), October 17-19, 2017. **Ralph Dubayah** [University of Maryland, College Park (UMD)—*GEDI Principal Investigator*] convened the meeting, with 29 SDT members and collaborators on the GEDI mission attending—see photo. The main objectives of the meeting were to review the science data products, the Algorithm Theoretical Basis Documents (ATBDs), the GEDI Science Planning System, and the status of external collaborative activities for calibration/validation and data fusion.



Participants of the Fourth GEDI Science Definition Team meeting. **Photo credit:** Hao Tang/University of Maryland [GEDI Science Team member]

## Mission Status

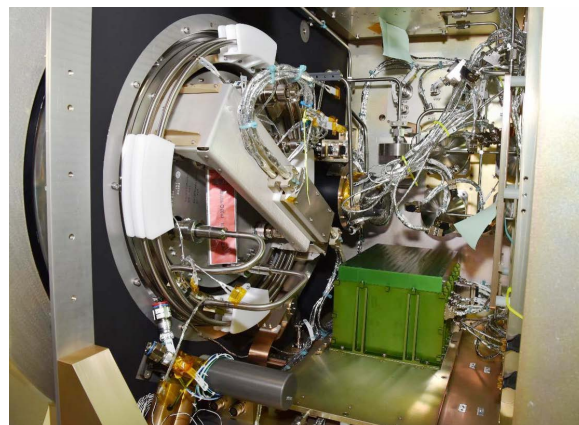
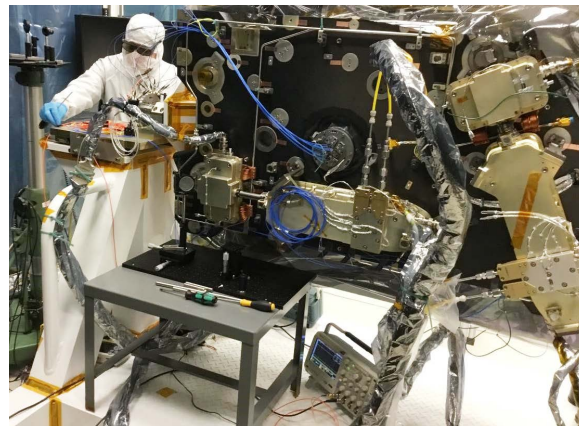
**Ralph Dubayah** opened the meeting with the announcement that GEDI's launch will be delayed until mid-2019 due to a delay with the SpaceX CRS-18 launch.<sup>1</sup> **Jim Pontius** [GSFC—*GEDI Project Manager*] provided an update to the SDT on the progress of the instrument build, which is currently in the Integration and Test phase and scheduled for completion in September of 2018. **Bryan Blair** [GSFC—*GEDI Deputy Principal Investigator and Instrument Scientist*] informed the team that most units of the GEDI instrument have been assembled and environmentally tested, and are ready for integration onto the spacecraft—see **Figure**. The GEDI SDT team is also on schedule to deliver the required calibrated

<sup>1</sup> **UPDATE:** Since the meeting, GEDI has been moved from the SpaceX CRS-18 mission, which is now delayed to May 2019, to SpaceX CRS-16. **This moves the launch date forward to November 2018**, which was the original launch date for GEDI.

and validated data algorithms. Version 1 of the GEDI ATBD documents, describing the data-processing procedures and algorithms for each data product, are near completion and will be released to the public early in 2018—see **Table** on page 18.

**John Armston** [UMD] and **Laura Duncanson** [UMD] have led the development of the GEDI Forest Structure and Biomass (FSB) database, essential for calibration and validation of the GEDI biomass products, which is undergoing rapid growth with sponsorship from NASA's newly created Multi-Mission Analysis Platform (MAP).<sup>2</sup> The current focus for the FSB Database is on quality control, importing new crowd-sourced data

<sup>2</sup> MAP is a pilot project jointly organized by NASA and ESA that is intended to facilitate the sharing of data, algorithm development, and analysis tools between scientific groups and agencies. It is being designed to provide cloud-based access to several upcoming active remote sensing datasets, as well as relevant airborne and field calibration and validation data.



**Figure.** The photo on the top shows the assembly of two flight lasers and beam dithering units on the flight optical bench; the photo on the bottom shows the flight pointing control mechanism, power converter unit, harness, and fluid loop in the flight structure. **Photo credit:** Jim Pontius

Table. Summary of GEDI's data products, ATBDs, ATBD authors, and product leads.

ATBD #	ATBD Title	Data Products Addressed	ATBD Authors/ Product Leads
Level-1A-2A	Transmit and Receive Waveform Interpretation and Generation of L1A and L2A Products	1A-TX: Transmitted waveform parameters 1A-RX: Received waveform parameters 2A: Elevation and relative height (RH) metrics	<b>Michelle Hofton</b> [GSFC] <b>James Bryan Blair</b> [GSFC]
Level-1B	Geolocated Waveforms	Geolocated waveforms	<b>Scott Luthcke</b> [GSFC] <b>Tim Rebold</b> [GSFC] <b>Taylor Thomas</b> [GSFC] <b>Teresa Pennington</b> [GSFC]
Level-2B	Footprint Canopy Cover and Vertical Profile Metrics	Footprint canopy cover and vertical profile metrics	<b>Hao Tang</b> [UMD] <b>John Armston</b> [UMD]
Level-3	Gridded Land Surface Metrics	Gridded L2A and L2B metrics	<b>Scott Luthcke</b> [GSFC] <b>Terence Sabaka</b> [GSFC] <b>Sandra Preaux</b> [GSFC]
Level-4A	Footprint Above Ground Biomass	Footprint above-ground biomass density	<b>Jim Kellner</b> [Brown University] <b>Laura Duncanson</b> [UMD] <b>John Armston</b> [UMD]
Level-4B	Gridded Biomass Product	Gridded above-ground biomass density	<b>Sean Healey</b> [U.S. Forest Service (USFS)] <b>Paul Patterson</b> [USFS]
Demonstration Products	No ATBD*	Prognostic ecosystem model outputs	<b>George Hurtt</b> [UMD]
		Enhanced height/biomass using fusion with the German Aerospace Center (DLR) TerraSAR-X add-on for Digital Elevation Measurement (TanDEM-X) Mission	<b>Lola Fatoyinbo</b> [GSFC] <b>Seung-Kuk Lee</b> [GSFC]
		Enhanced height/biomass using fusion with Landsat	<b>Matt Hansen</b> [UMD] <b>Chenquan Huang</b> [UMD]
		Biodiversity/habitat model outputs	<b>Scott Goetz</b> [Northern Arizona University (NAU)] <b>Patrick Jantz</b> [NAU]

\* There are no ATBDs for the demonstration products since these products are not funded under the GEDI mission.

projects, and facilitate the MAP goals by coordination with other NASA and European Space Agency (ESA) missions, such as the NASA-Indian Space Research Organisation (ISRO) Synthetic Aperture Radar (SAR) [NISAR] mission.

**Steven Hancock** [UMD] reported on the development of the GEDI performance tool. The tool simulates GEDI measurements that are then passed through the GEDI processing chain to assess the impact of different instrument configurations, environmental conditions, and associated data processing decisions on final products.

### Science Data Processing and Analysis Status

**Scott Luthcke** [GSFC] described the GEDI Data Management Plan, the Science Operation Center, and the Mission Operation Center. He discussed the status of the week-in-the-Life (WITL) simulation, which is a planning simulation of the tasks to be performed during GEDI mission operations. GEDI will have a 14-day planning cycle during which the data collection plan is generated, accepted or rejected, revised accordingly, and executed. The plan contains all information essential to instrument parameter settings and regions of interest to be targeted. One of the team's priorities for the next SDT meeting is delivering data layers to assist in planning the mission.

## Collaborations and Data Fusion Products

**Patrick Jantz** [Northern Arizona University (NAU)], **Scott Goetz** [NAU—*Deputy PI*], and **Patrick Burns** [NAU], in collaboration with the World Wildlife Fund in Columbia and the Humboldt Institute Columbia (IAvH), are currently analyzing the relationships between structure, floristic diversity, and environmental variables in South America. This is being done to develop a method to estimate biodiversity using environmental variables and GEDI structural metrics.

**Matt Hansen** [UMD] and **Chenquan Huang** [UMD] presented material on the use of the GEDI biomass products in combination with the Landsat Forest Cover Change product. Their current focus is on developing methods to estimate carbon loss related to forest-cover change. They are also investigating the potential of GEDI to estimate the carbon sequestration rate by substituting space for time-since-disturbance, using the Landsat change product. The Landsat land cover change product will be used in combination with the GEDI biomass product to calculate the amount of accumulated biomass since last disturbance, providing a measure of the carbon sequestration that has taken place since disturbance.

**Matteo Pardini** [German Aerospace Agency (DLR)] described a project that he did with GEDI STM members **Wenlu Qi** [UMD] and **John Armston** [UMD], on retrieval of vertical profiles of the vegetation canopy from TanDEM-X<sup>3</sup> using simulated GEDI data during Pardini's visit to UMD during July and August of 2017.

**Seung-Kuk Lee** [GSFC] and **Lola Fatoyinbo** [GSFC] presented recent results on the use of simulated GEDI topographic data with the continuous coherence images from TanDEM-X to improve the accuracy and resolution of Digital Terrain Models (DTM) derived from TanDEM-X and subsequent canopy-height retrievals.

The Research Coordination Network (RCN) Terrestrial Laser Scanning (TLS) field campaign, coordinated by **Crystal Schaaf** [University of Massachusetts] and colleagues, has resulted in new biomass calibration/validation data with highly accurate validation biomass values. Schaaf described the experiment in which the same trees were scanned using five different types of TLS instruments to facilitate intercomparison of

<sup>3</sup> TanDEM-X is a German Earth-observing mission, which seeks to generate an accurate three-dimensional image of Earth that is homogeneous in quality and unprecedented in accuracy. TanDEM-X flies in formation with its "twin," TerraSAR-X, which seeks to add value-added Synthetic Aperture Radar (SAR) data in the X-band for research and development, as well as for scientific and commercial applications. Learn about both these missions at [http://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10378/566\\_read-436/#/gallery/345](http://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10378/566_read-436/#/gallery/345).

the measurements obtained by each type of instrument. Vegetative samples from each tree were also harvested and weighed in order to improve biomass models, which use TLS data as input. These data will help constrain the GEDI biomass models by providing more-accurate field-reference data.

**Laura Duncanson** [UMD] and **John Armston** are co-leading the Committee on Earth Observation Satellites (CEOS) Land Product Validation (LPV) biomass focus area to support cross-mission calibration and validation of biomass products. An investigation on high biomass estimates, led by **Laura Duncanson**, **Lola Fatoyinbo**, and **Amy Neuenschwander** [all from GSFC], is showing promising results to improve estimation of overall GEDI biomass. Additionally, the potential of using similarly structured biomass algorithms for both GEDI and Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) lidar data is being investigated with the goal of producing a merged, global biomass product from both missions.

**Andreas Huth**, **Rico Fisher**, and **Nikolai Knapp** [all at Helmholtz Institute (HI) in Germany] attended the meeting as invited guests and shared their expertise with the FORMIND model,<sup>4</sup> which can be used to simulate biomass stocks by modeling the growth of individual trees. They described how they ran the FORMIND model for the Amazon, in order to help determine whether the Amazon is a carbon sink or source. ICESat forest-height data were used as model input to constrain tree height. GEDI will provide an order of magnitude more canopy height data at higher resolution than ICESat. Once these data are available, ecosystem models such as FORMIND will produce far more realistic and accurate simulations than are currently possible.

## Conclusion

The fourth GEDI SDT meeting was a great success. The team is making good progress on the ATBDs and will soon make them publicly available. The current focus is largely on improving the calibration and validation dataset and allowing for collaboration with scientists from other NASA/ESA missions related to biomass estimation. Having those external collaborators attend the GEDI SDT meeting also allowed for fruitful conversations, new insights, and promising applications of the coming GEDI data. The team will convene their next meeting in April 2018. ■

<sup>4</sup> FORMIND is an individual-based vegetation model that simulates the growth of species-rich forests on the hectare scale. It includes gap formulations in order to display forest dynamics and forest structure. For more information, visit <http://formind.org>.

## Summary of the Eighth CYGNSS Science Team Meeting

Derek Posselt, NASA/Jet Propulsion Laboratory, [derek.posselt@jpl.nasa.gov](mailto:derek.posselt@jpl.nasa.gov)

Christopher Ruf, University of Michigan, [cruf@umich.edu](mailto:cruf@umich.edu)

### Introduction

The eighth Cyclone Global Navigation Satellite System (CYGNSS) Science Team Meeting was held at the National Oceanic and Atmospheric Administration (NOAA) Atlantic Oceanographic and Meteorological Laboratory (AOML) in Miami, FL, December 18-19, 2017. **Christopher Ruf** [University of Michigan—*Mission Principal Investigator (PI)*] and **Derek Posselt** [NASA/Jet Propulsion Laboratory (JPL)—*Science Team Lead*] planned and convened the meeting, while **Robert Atlas** [NOAA AOML] was the host. The meeting featured updates on the status of the CYGNSS spacecraft and its data products, as well as early science highlights from this NASA Earth Venture mission.<sup>1</sup>

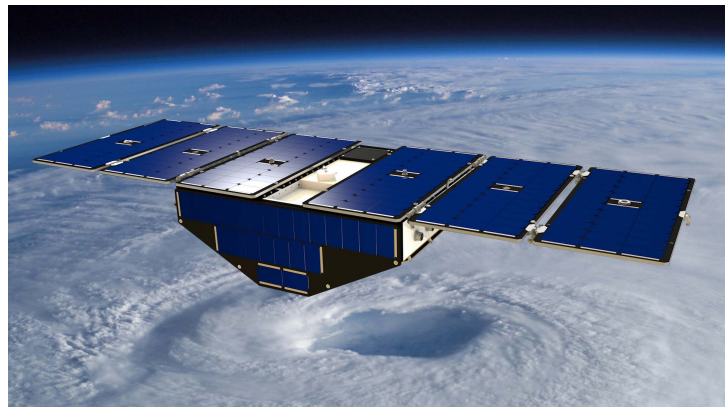
CYGNSS consists of a constellation of eight small satellites, each designed to measure ocean surface wind speed at 25-km (~15-mi) resolution over a region that spans approximately 38° N and 38° S latitude. This range includes the critical latitude band for tropical cyclone (TC) formation and movement. CYGNSS was launched from Cape Canaveral, FL, on December 15, 2016, aboard an Orbital ATK Pegasus XL rocket. Data products are available from the Physical Oceanography Distributed Active Archive Center (PO.DAAC), with data products produced since March 18, 2017.

CYGNSS measures reflected radar signals from the Global Positioning System (GPS) constellation. Scattering of the GPS signal from the ocean surface is proportional to the local wind speed, which gives rise to CYGNSS's estimates of ocean surface winds. The L-band [19-cm wavelength] GPS signal is minimally attenuated by precipitation, allowing CYGNSS to provide ocean surface wind estimates in regions with heavy precipitation. More specifically, the mission focuses on measurements of wind speeds in and around the inner core of TCs—an area that heretofore has been difficult to observe. A constellation of eight spacecraft in a low-inclination (35°) orbit allows for frequent observations of winds (7.2-hour mean revisit time) over the global tropical and subtropical ocean. These

<sup>1</sup>The NASA Science Mission Directorate/Earth Science Division's (SMD/ESD) Earth Venture is a Program element within the Earth System Science Pathfinder Program (ESSP) consisting of a series of new science-driven, competitively selected, low cost missions. For more information, visit <https://eosps.nasa.gov/mission-category/13>.

measurements should lead to improving our understanding of TC inner-core processes, and ultimately to improved TC-intensity and -track forecasts.<sup>2</sup>

The eighth CYGNSS Science Team Meeting included 29 presentations from various science team members. Mission overview information and supporting documentation is available at <http://www.cygnss-michigan.org>. Presentations from the meeting are available to the CYGNSS science team—but have not been made publically available.



Artist's rendition of one of eight CYGNSS constellation spacecraft in low Earth orbit. **Image credit:** Southwest Research Institute

### CYGNSS Mission Status and Constellation Configuration

All eight of the CYGNSS spacecraft are in good working order and collecting data with a near-100% duty cycle. The observatories were grouped on a single launch vehicle and have been gradually dispersing into their respective orbital tracks during the past year to improve their sampling statistics. The spacecraft carry no propulsion systems; rather, constellation spacing is adjusted by performing “drag maneuvers,” in which one or more spacecraft at a time are tilted so that the solar panels are approximately perpendicular to the tenuous upper atmosphere, present even at orbital altitude. The additional drag induced by this configuration causes a small decrease in altitude and resultant increase in orbital velocity relative to the rest of the constellation,

<sup>2</sup>To learn more about CYGNSS, read “Eight Microsatellites, One Mission: CYGNSS” in the November-December 2016 issue of *The Earth Observer* [Volume 28, Issue 6, pp. 4-13]—[https://eosps.nasa.gov/sites/default/files/eo\\_pdfs/Nov-Dec%202016%20color%20508.pdf](https://eosps.nasa.gov/sites/default/files/eo_pdfs/Nov-Dec%202016%20color%20508.pdf).

allowing spacecraft to be repositioned one by one. CYGNSS is the first mission for which differential drag has been used in maintaining constellation spacing.

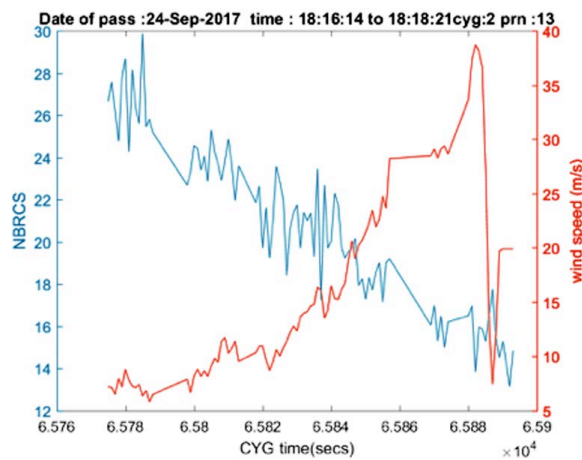
### CYGNSS Observations of the 2017 Atlantic Hurricanes

The CYGNSS constellation was in orbit and performing nominally during the entirety of the unusually active 2017 Atlantic hurricane season. Because of the exceedingly strong winds and highly disturbed sea state in major hurricanes, it is very difficult to derive reliable reference wind speed data from numerical weather prediction models with which to evaluate CYGNSS retrievals. For this reason, coincidence with validation data gathered with the NOAA P3 Orion “Hurricane Hunter” aircraft is especially useful. During the 2017 Atlantic hurricane season, CYGNSS data were matched to stepped frequency microwave radiometer (SFMR) data, which can estimate surface winds in hurricanes, and dropsonde data from the P3 Orion for every named storm—most notably, the destructive hurricanes Harvey, Irma, and Maria. Comparison between the CYGNSS normalized bistatic radar cross section (NBRCS)<sup>3</sup> and the SFMR-estimated surface winds show that the CYGNSS signal does not saturate, even at surface wind speeds up to 60 m/s (~134 mph)—see **Figure**.

### CYGNSS Calibration and Validation and Baseline Data Products

Data from CYGNSS consist of the Level-1 (L1) Delay Doppler Map (DDM), which is effectively a map of the diffuse scattering from the ocean surface in a two-dimensional coordinate system consisting of GPS time delay and Doppler frequency shift. Each coordinate is relative to the specular reflection point on the Earth’s surface. Level-2 (L2) products, estimated from the L1 data, include ocean surface wind speed and the mean square slope (MSS) of the ocean surface. A Level-3 (L3) gridded wind speed product is produced from the L2 wind speed estimates at 0.2-degree spacing and hourly time intervals. Several Level-4 (L4) products, including estimates of tropical cyclone radius of maximum winds, maximum wind speed, and integrated kinetic energy are being developed. Version 2 of the L1 and L2 products was released in December 2017, two weeks prior to the meeting.

In the time since the previous science team meeting in May 2017, the CYGNSS Science Team has made significant progress in calibrating and validating the CYGNSS data. The key personnel involved in the L1 calibration effort are **Scott Gleason** [University Corporation for Atmospheric Research (UCAR)], **Darren McKague** [University of Michigan], **Andrew O’Brien** [Ohio State



**Figure.** Coincident measurements of ocean surface wind speed by stepped frequency microwave radiometer (SFMR) on P3 Orion “Hurricane Hunter” aircraft [right vertical axis, darker plot] and the CYGNSS normalized bistatic radar cross section (NBRCS) [left vertical axis, lighter plot] during a simultaneous overpass of Hurricane Maria on September 24, 2017 at 18:17 UTC. As the wind speed increases, so does the ocean surface roughness—which is what CYGNSS measures directly from space. As the ocean surface roughens, it diffusely scatters a larger portion of the GPS signal, resulting in smaller NBRCS in the specular direction with increasing wind speed. **Image credit:** University of Michigan.

University], **Tianlin Wang** [University of Michigan], **Zorana Jelenak** [NOAA], **Paul Chang** [NOAA], **Faozi Said** [NOAA], and **Golf Soisuvarn** [NOAA]. The major L1 calibration issues that have been addressed include:

- More-accurate estimates of specular point location;
- corrections to the CYGNSS antenna gain pattern;
- improved characterization of GPS transmitter power and antenna gain patterns; and
- more-accurate binning and averaging of the reflected power around each specular point.

The improvements in the L1 calibration have resulted in far better agreement between CYGNSS L2 winds and independent datasets, most notably numerical weather prediction model outputs from the NOAA Global Data Assimilation System and the European Centre for Medium-range Weather Forecasts, as well as more-detailed attribution and quantification of uncertainty.

In addition to L1 calibration improvements, there have been advances in generating the geophysical model function (GMF) used to retrieve the L2 winds. Key personnel working on the L2 retrievals are **Chris Ruf**, **Maria-Paola Clarizia** [University of Southampton, U.K.], **Rajeswari Balasubramaniam** [University of Michigan], and **Valery Zavorotny** [NOAA].

Since the May 2017 Science Team Meeting, underflights of CYGNSS by the NOAA P3 Orion aircraft and match-ups with its SFMR and dropsonde data revealed that there were two different dependencies

<sup>3</sup>This is equivalent to the average radar cross-section of a set of objects per unit area.

of the CYGNSS DDM signal on the surface wind. In particular, the functional dependence between L1 data and surface wind speeds differ between regions for which winds are relatively light [ $< 20$  m/s ( $\sim 45$  mph)] and the *fetch*<sup>4</sup> is long, and regions with strongly curved flow and strong [ $> 20$  m/s] wind speeds. This is due to the fact that the wind speed and wave spectrum will be out of equilibrium to an extent that depends on the acceleration of the wind. This has resulted in the release of two distinct wind retrieval products, which include:

- a *fully developed seas* wind retrieval, based on global match-ups between the L1 data and gridded surface wind speed data from operational analyses; and
- a *young-seas/limited-fetch* wind retrieval, based on match-ups between L1 data and SFMR and dropsonde data in high winds.<sup>5</sup>

In addition to the ocean surface winds, the MSS of the ocean surface is also retrieved from the scattering cross-section of the ocean surface. **Valery Zavorotny** is the lead scientist in the development of MSS retrievals. This MSS retrieval has been shown to include a component due to the local winds, and to nonlocally generated longwave swell. The science team is actively working on distinguishing the local and nonlocal portions of the wave spectrum signal.

### CYGNSS Soil Moisture and Inundation Signal

Several investigators, including **Cinzia Zuffada** and **Mary Morris** [both at JPL], and **Clara Chew** [UCAR], have identified a soil moisture and inundation fraction signal in reflected GPS signals from land. There is not, as yet, a retrieval algorithm for either soil moisture or inundation fraction; however, comparisons among CYGNSS received-power and soil-moisture estimates from the Soil Moisture Active-Passive (SMAP) mission indicate the clear presence of such a signal in the CYGNSS data. The relatively high resolution of the CYGNSS data, along with the rapid revisit, make this a promising new area of research and development for the mission.

### Non-TC Science Highlights

In addition to the primary mission focus on TCs, CYGNSS data are being used to examine a range of

other atmospheric phenomena. Several science team members have been supported since before launch to explore the use of CYGNSS data for:

- *Analyzing winds in and around non-TC organized convection in the tropics*. This effort is multifaceted, with **Tim Lang** [NASA's Marshall Space Flight Center (MSFC)] conducting research on the analysis of gust-front and cold pool signals associated with deep convection. Further, **Duane Waliser** [JPL], **Eric Maloney** [Colorado State University (CSU)], **Emily Riley Dellaripa** [CSU], **Susan van den Heever** [CSU], and **Xiaowen Li** [NASA's Goddard Space Flight Center (GSFC)] are studying the development and evolution of large scale, convectively coupled waves.
- *Examination of the properties of low-latitude extratropical fronts and cyclones, including the influence of surface sensible and latent heat fluxes*, with **Derek Posselt** [JPL] and **Juan Crespo** [University of Michigan] leading this effort.
- *Assimilation of CYGNSS data into numerical models, spanning scales from global to regional*. **Bob Atlas** [NOAA AOML], **Sharan Majumdar** [University of Miami], **Mark Leidner** [Atmospheric and Environmental Research], **Brian McNoldy** [NOAA AOML], **Zhaoxia Pu** [University of Utah], **Timothy Lang** [MSFC], and **Nancy Baker** [National Research Laboratory, Monterey] are all part of this effort.

### Summary and Near-Term Plans

The meeting concluded with a group discussion centered on the next set of calibration and validation activities, as well as near-term science priorities. Priorities for calibration and validation and data-product generation include accurately characterizing the GPS antenna patterns using a ground-based GPS receiver, and the use of wave models to extract the longwave swell signal from the CYGNSS bistatic radar cross section. Science priorities include analyzing data from the 2017 hurricane season, continuing exploration of CYGNSS wind speed signals in non-TC deep convection, analyzing the ocean surface wave spectrum retrieved from CYGNSS, and examining extratropical storms that form at low-latitudes during the 2017-18 boreal winter.

The next CYGNSS Science Team Meeting is scheduled for June 2018. ■

<sup>4</sup>In this context, *fetch* refers to the horizontal distance over which wave-generating winds blow.

<sup>5</sup>The external (i.e., the SFMR and dropsonde) data are used to develop a functional relationship between the CYGNSS L1 signal and the wind speed. This function is then used to generate wind from the L1 NBRCS and LES. In essence, one can think of the gridded wind speed estimates and SFMR data as "training data."

# 2017 Ocean Surface Topography Science Team Meeting

Joshua Willis, NASA/Jet Propulsion Laboratory, [joshua.k.willis@jpl.nasa.gov](mailto:joshua.k.willis@jpl.nasa.gov)

Pascal Bonnefond, Laboratoire Géoazur, Observatoire de la Côte d'Azur, Centre National d'Études Spatiale, [pascal.bonnefond@obs-azur.fr](mailto:pascal.bonnefond@obs-azur.fr)

## Introduction

The 2017 Ocean Surface Topography Science Team (OSTST) Meeting was held in Miami, FL, October 23-27, under the theme, “The 25<sup>th</sup> Anniversary of TOPEX/Poseidon.” In celebration of the 25-year duration of the successful NASA–Centre National d'Études Spatiale (CNES) ocean altimetry missions, this meeting included special splinter sessions on analysis of currently available synthetic aperture radar (SAR) data with a focus on benefits for coastal areas and other water surfaces.

The primary objectives of the OSTST Meeting were to:

- provide updates on the status of Jason-2 and Jason-3;
- conduct splinter meetings on system performance (i.e., orbit, measurements, corrections, and advances in SAR processing), altimetry data products, science outcomes, and outreach; and
- hold special splinter sessions on coastal and cryospheric and hydrological altimetry.

The meeting lasted five days to allow time for discussions during dedicated roundtables for each splinter group. A report of the meeting, along with all of the presentations from the plenary, splinter, and poster sessions, is available on the Archiving, Validation, and Interpretation of Satellite Oceanographic data (AVISO) website at <http://meetings.aviso.altimetry.fr>.

## Status Report on Current Ocean Surface Topography Missions

Jason-3 was launched from Vandenberg Air Force Base on January 17, 2016, on a SpaceX Falcon 9 v1.1 vehicle; all of its systems and instruments are operating nominally. After flying in tandem approximately 80 seconds behind Jason-2 for a period of six months while data were evaluated, Jason-3 became the new reference altimetry mission on June 21, 2016. After that, Jason-2 was moved into an interleaved orbit in October 2016 on an adjacent ground track with a five-day lag behind Jason-3. This orbit was identical to the one flown by Jason-1, and was designed to provide improved spatial and temporal coverage of sea surface height observations.

Launched in June 2008, Jason-2 remains in operation and continues to provide data of excellent quality—but with reduced availability due to issues with the satellite's attitude control system. In March 2017, after about

five months in its interleaved orbit, Jason-2 began to have issues with this mission-critical system. In July 2017 Jason-2 was moved to a Long Repeat Orbit (LRO) (colloquially referred to as the *geodetic orbit*) approximately 27 km (-17 mi) below the reference orbit as the OSTST had recommended in 2016. Despite some prolonged data outages between March and July of 2017, the satellite has resumed operation and is expected to continue to operate nominally at about a 70% duty cycle. Occasional outages caused by warming of the satellite during certain phases of its orbital precession are expected to occur every few months, lasting for a few weeks at a time. During the 2017 meeting the OSTST carefully assessed the impact of these outages. In light of this assessment, the OSTST adopted two recommendations:

1. As long as Jason-2 remains in the LRO, it provides valuable data for operational users and for improvements in mean sea surface estimates despite gaps created by safe holds. The OSTST therefore encourages efforts to minimize future Jason-2 gyroscope failures.
2. The OSTST recognizes that valuable geodetic measurements can be made in the Jason-2 LRO even if some performance is degraded, such as the loss of the radiometer. The OSTST recommends consulting the Extension-of-Life (EoL) group<sup>1</sup> if rapid decisions need to be made.

Since the 2017 OSTST Meeting, the four partner agencies [CNES, National Oceanic and Atmospheric Administration (NOAA), European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), and NASA] have jointly agreed to extend the operations of the Jason-2 mission through the end of calendar year 2019, in recognition of the importance of Jason-2 data to both the scientific and operational communities.

Finally, there was discussion about the next planned Ocean Surface Topography mission, the Copernicus Sentinel-6<sup>2</sup>/Jason Continuity of Service (hereafter, Jason-CS), which aims to continue the high-precision

<sup>1</sup> The EoL group is a small panel of experts selected by the OSTST leadership from the altimeter science and operational communities to provide advice on orbit selection for the aging satellite altimeters.

<sup>2</sup> The Sentinel Missions are part of the European Space Agency's (ESA) Copernicus Programme. They are detailed at [http://m.esa.int/Our\\_Activities/Observing\\_the\\_Earth/Copernicus/Overview4](http://m.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Overview4).

ocean altimetry measurements in the 2020–2030 time-frame via two successive identical satellites (Jason-CS-A and Jason-CS-B). Jason-CS is now in full development and the partner Agencies (EUMETSAT, European Space Agency (ESA), NASA, and NOAA with CNES providing support) informed OSTST of progress to date.

### Opening Plenary Session Highlights

**Pascal Bonnefond** [CNES—*Jason Project Scientist*] began with welcoming remarks on behalf of all the project scientists, which (in addition to himself) includes **Josh Willis** [NASA/Jet Propulsion Laboratory (JPL)], **Eric Leuliette** [NOAA], **Remko Scharroo** [EUMETSAT], and **Craig Donlon** [ESA].

**Katherine Hagemann** [Miami-Dade County Office of Resilience—*Resilience Program Manager for Adaptation*] gave a special presentation on local sea-level-rise impacts in Miami-Dade County. She discussed the numerous efforts being planned and undertaken there to improve resiliency against flooding and other local impacts due to sea-level rise.

**Lisa Beal** [University of Miami, Rosenstiel School of Marine and Atmospheric Sciences (RSMAS)—*Oceanographer*] gave an invited presentation titled “Broadening Not Strengthening: A 24-Year Altimeter Proxy for the Agulhas Current.” With co-author **Shane Elipot** (RSMAS), Beal described how she used satellite altimeter observations to reconstruct both the strength and width of the Agulhas Current, a powerful western boundary current that rounds the southern tip of Africa before returning west—see **Figure 1**. The current,

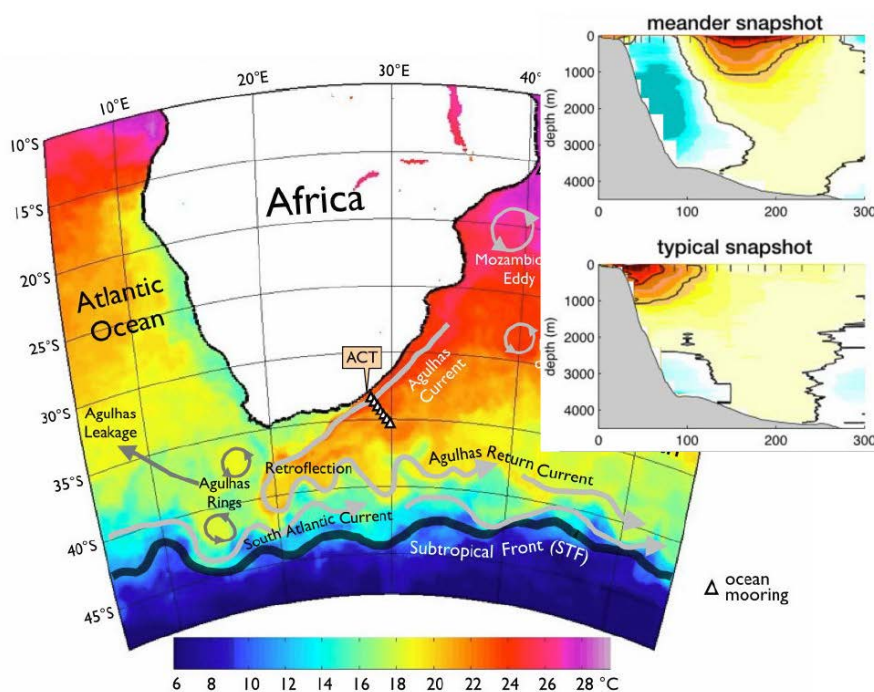
which has broadened but not strengthened over the past 22 years, plays a key role in the transport of heat and ocean overturning circulation.

After Beal’s presentation, **Nadya Vinogradova** [Cambridge Climate Institute, Massachusetts] representing NASA, **Juliette Lambin** [CNES], **François Parisot** [EUMETSAT], **Eric Leuliette** [NOAA], and **Jérôme Benveniste** [ESA]—the program managers representing each of the partner organizations—presented the status of altimetry and oceanographic programs at their respective agencies.

### Status Report on Future Altimeter Missions

During the opening plenary session, participants heard updates on upcoming and ongoing missions of interest to the altimetry science community. These included Jason-CS, which is on track to launch Jason-CS-A in late 2020; Satellite with ARgos and ALtiKa (SARAL),<sup>3</sup> which continues to perform well after more than four years on orbit; Copernicus Sentinel-3, a set of high-inclination altimeters, the first of which launched in February 2016 and is still operating nominally, with its second satellite set to launch in early 2018; China France Oceanography Satellite (CFOSAT), a wind and wave scatterometer mission to be launched in September 2018; and finally, NASA’s Surface Water Ocean Topography (SWOT) mission, a high-resolution swath altimeter for the ocean, lakes, and rivers, is on track to be launched in 2021.

<sup>3</sup>SARAL is a cooperative altimetry technology mission between the Indian Space Research Organisation and CNES.



**Figure 1.** This map shows the currents surrounding the southern tip of Africa, including the Agulhas Current and its retroflexion (i.e., change in direction) and return current. The set of symbols labeled “ACT” shows the locations of a set of moorings as part of the Agulhas Current Time-series Projects. The inset shows the Agulhas current as measured by the moorings at different times, once during a meander, where the entire current moves offshore [*top inset*] and a more-typical time, when the current hugs the shelf break [*bottom inset*]. **Image credit:** Lisa Beal



### Keynote Science Session

A special Keynote Science Session following the Plenary Session included four invited presentations. **Christopher Watson** [University of Tasmania], discussed estimates of global mean sea-level rise based on the satellite altimetry record. **Shenfu Dong** [University of Miami, Cooperative Institute for Marine and Atmospheric Studies (CIMAS), and NOAA/Atlantic Oceanographic and Meteorological Laboratory] described changes in the South Atlantic Meridional Overturning Circulation. **Lynn Shay** [RSMAS] presented satellite-derived estimates of ocean heat content. Finally, **Jean Tournade** [L'Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER)] presented estimates of iceberg populations around Greenland and Antarctica, derived from CryoSat-II Synthetic Aperture Radar Interferometric (SARIn) data.

### Splinter Session Highlights

Following the opening plenary session, the following focused splinter sessions took place, titled:

- Application Development for Operations;
- Instrument Processing: Corrections, Measurement, and Retracking;
- Outreach, Education, and Altimetric Data Services;
- Precise Orbit Determination;
- Quantifying Errors and Uncertainties in Altimetry Data;
- Regional and Global Calibration/Validation for Assembling a Climate Data Record;
- The Geoid, Mean Sea Surfaces, and Mean Dynamic Topography;
- Tides, Internal Tides, and High-Frequency Processes;
- Advances in Coastal Altimetry: Measurement Techniques, Science Applications, and Synergy with *in situ* Measurements and Models; and
- Science Results from Satellite Altimetry:
  - Mesoscale and Sub-Mesoscale Oceanography; and
  - 25 Years of Satellite Altimetry for Cryosphere and Hydrology: From Experimental to Emerging Operational Applications.

A key highlight from one of these science splinters is discussed below. Complete coverage of the results can be found at the AVISO website mentioned in the Introduction.

### Science Results from Satellite Altimetry

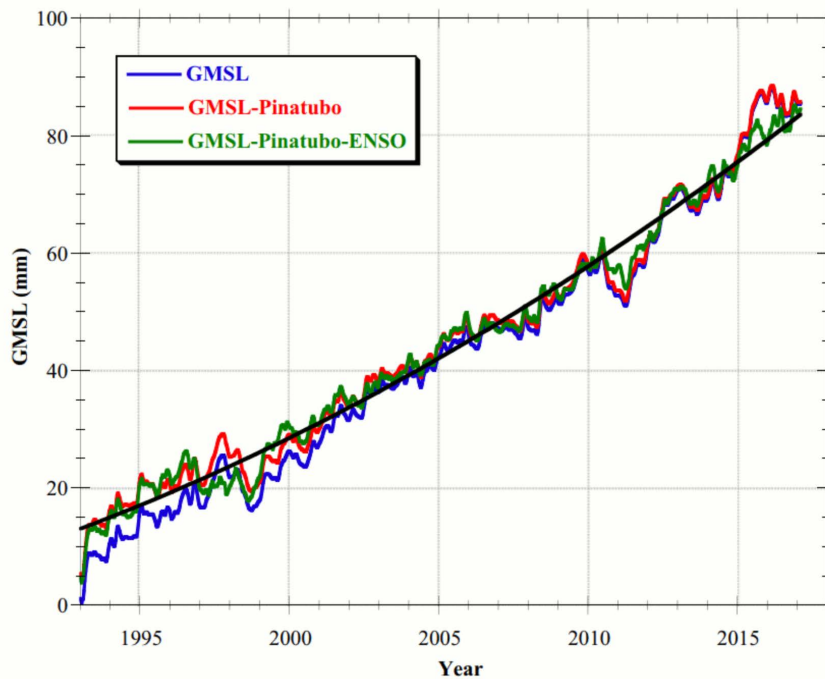
A discussion of the record of global sea-level rise based on satellite altimeter observations is worthy of more description. This took place during the broader discussion of climate data records for understanding the causes of global and regional sea level variability and change during the Science Results for Satellite Altimetry splinter session. **Steve Nerem** [University of Colorado Boulder] presented results showing that if the record of small year-to-year changes in global sea level was caused by both natural cycles (like El Niño and La Niña) and singular events (like the global cooling caused by the 1992 eruption of Mount Pinatubo) are taken into consideration, then a small acceleration in the rate of global sea level rise was detectable over that 24-year record—see **Figure 2** on page 26.

### Closing Plenary Session Highlights

**Paolo Cipollini** [National Oceanography Centre, U.K.] began the closing plenary session with a summary of the Tenth Coastal Altimetry Workshop, held in Florence, Italy, February 21-24, 2017. Then, a representative from each splinter session provided a summary of their group's deliberations and raised key points for discussion.

Also during the closing session, the OSTST's splinter groups raised a number of recommendations. In addition to the two recommendations pertaining to continued operation of Jason-2 mentioned earlier, the OSTST also expressed support for an upcoming ESA initiative called Fiducial Reference Measurements for Altimetry (FRM4ALT). The first meeting of this initiative's participants will be held in Chania, Crete, April 23-25, 2018, and will focus in long-term ground-based calibration sites for altimetry (<http://www.frm4alt.eu/int-cal-val-review>).

Discussion followed on the importance of continuing the long-term climate record collected by all historical satellite altimeters. The deliberations resulted in the adoption of an additional recommendation, recognizing the importance of regular reprocessing of historical



**Figure 2.** This graph shows globally averaged sea level rise from the satellite record (blue), from the same record but corrected for the cooling caused by the 1992 eruption of Mount Pinatubo (red), and also corrected for the natural cycles of El Niño and La Niña (green). The black line shows a quadratic fit with an acceleration of  $0.084 \text{ mm/year}^2$ , representing an increase in the rate of rise of  $0.84 \text{ mm/year}$  ( $-0.03 \text{ in/year}$ ) per decade. **Image credit:** Steve Nerem

missions with common standards that are at the level of current missions. Other specific recommendations can be found in the splinters summaries online at <https://www.avisio.altimetry.fr/en/user-corner/science-teams/ostst-swt-science-team/ostst-2017-miami.html>.

As has become customary, this OSTST meeting ended with a number of acknowledgements and kudos, several of which refer to recommendations made by the OSTST. The team recognized the four partner agencies for the successful move of Jason-2 to its LRO, and for the recovery of Jason-2 after the multiple issues involving the gyroscopes. In addition, the group thanked the Jason-2 and Jason-3 projects for the effort made to increase the number of cold-sky calibration maneuvers for the Jason-2 and Jason-3 radiometers. Additional acknowledgements can be found in the full OSTST meeting report link in the Introduction.

## Conclusion

Overall, the meeting was very successful, having fulfilled all its objectives. It provided a forum for an update on the status of Jason-2 and Jason-3 and other relevant missions and programs, and for detailed analyses of the observations by the splinter groups.

The 2018 OSTST meeting will be held September 24-29, in Ponta Delgada, Azores, Portugal, in conjunction with the *25 Years of Progress in Radar Altimetry* symposium. ■

# NASA High Mountain Asia Team Precipitation Workshop Summary

Batu Osmanoglu, NASA's Goddard Space Flight Center, [batuhan.osmanoglu@nasa.gov](mailto:batuhan.osmanoglu@nasa.gov)

Dalia Kirschbaum, NASA's Goddard Space Flight Center, [dalia.b.kirschbaum@nasa.gov](mailto:dalia.b.kirschbaum@nasa.gov)

Viviana Maggioni, George Mason University, [vmaggion@gmu.edu](mailto:vmaggion@gmu.edu)

Stephen Nicholls, NASA's Goddard Space Flight Center, [stephen.d.nicholls@nasa.gov](mailto:stephen.d.nicholls@nasa.gov)

## Introduction

The NASA High Mountain Asia Team (HiMAT) was founded in the fall of 2016 to improve our understanding of the High Mountain Asia (HMA) region and the changes it is undergoing due to a changing climate, using the latest advances in remote sensing and modeling. Within the HiMAT team, a precipitation-focused subgroup composed of 19 team members has been tasked with simulating and measuring precipitation in HMA and its links to regional climate, the cryosphere, and the hydrologic cycle. On October 12-13, 2017, this subgroup participated in a two-day workshop at NASA's Goddard Space Flight Center (GSFC) to discuss and share results and analysis techniques associated with their ongoing precipitation measurement and modeling efforts over HMA and to foster collaboration amongst the team. The workshop structure provided opportunities to understand commonalities and differences among existing observational datasets, modeling approaches, and methods for model intercomparison. This article provides an overview of the meeting. While the presentations for this meeting were not posted, the agenda and some additional notes about the meeting can be found at <https://himat.org/event/precipitation-workshop>.

## Session A: Updates on HiMAT Research

Precipitation is a crucial component of water balance in HMA, but our present understanding is hampered by limited ground observations, complex terrain-precipitation interactions in a region of highly varying topography, and challenges associated with accurately characterizing the intensity, timing, and type of precipitation.

The HiMAT leverages its collective expertise in modeling and remote sensing data analysis to address this challenging research problem. During the first session, participants learned new ways to assemble and evaluate existing precipitation products and use state-of-the-art weather forecast and climate system models to study precipitation in this region.

**Sujay Kumar** [GSFC] presented his research using the Land Information System<sup>1</sup> over HMA. He explained that the Modern-Era Retrospective analysis for Research

<sup>1</sup>The Land Information System (LIS) is a software framework for high performance terrestrial hydrology modeling and data assimilation developed with the goal of integrating satellite and ground-based observational data products and advanced modeling techniques to produce optimal fields of land surface states and fluxes. To learn more, visit <https://lis.gsfc.nasa.gov>.

and Applications, Version 2 (MERRA-2)<sup>2</sup> dataset is distributed with both a model-generated (uncorrected) precipitation product, and a second product that is corrected to ground observations. Kumar compared both of these MERRA-2 precipitation products to three additional observational precipitation products [CHIRPS, APHRODITE, and IMD],<sup>3</sup> which are three products that combine the information from models, satellite remote sensing, and ground observations. He showed that the corrected MERRA-2 precipitation product compared well with these reference products—relative to the uncorrected product. Kumar also employed the comparison of land-model outputs (snow depth, snow cover, and streamflow) as an indirect evaluation of the input precipitation datasets. The precipitation inputs had a significant influence on the skill of the streamflow and snow depth outputs. In particular, the corrected MERRA-2 precipitation inputs were found to cause a *dry bias* in the snow depth and streamflow estimates. This discrepancy needs to be investigated in future work.

**Summer Rupper** [University of Utah] and **William Christensen** [Brigham Young University (BYU)] together provided an overview of the dominant patterns in precipitation timing and intensity across the HMA region. Rupper shared results from the Weather Research and Forecasting (WRF) model used to down-scale precipitation measurements across the HMA. Their WRF simulations used a double-nested model grid with 36-, 12-, and 4-km (-22-, 7-, and 2.5-mi, respectively) horizontal grid spacing based on data from 2000 and 2008. Rupper reported that the largest scale differences are dominated by the summer monsoon and differences in the resolved topography causing differences in the rain shadow areas. Different grid resolutions impacted both precipitation amount and its distribution, where differences in accumulated precipitation varied by approximately 2 m (-7 ft) between the finest and coarsest model grids. These results may provide further insights into use of coarse-resolution products and methods for downscaling to the resolutions needed for glacier mass-balance modeling. Christensen

<sup>2</sup>MERRA-2 is the latest atmospheric reanalysis of the modern satellite era produced by the Global Modeling and Assimilation Office (GMAO) at GSFC.

<sup>3</sup>CHIRPS stands for Climate Hazards Group Infrared Precipitation with Station data; APHRODITE stands for Asian Precipitation-Highly-Resolved Observational Data Integration Towards Evaluation; and IMD stands for India Meteorological Department.

described several statistical approaches for extracting consensus among the multitude of precipitation products currently available, and for estimating the biases between model-derived and observational precipitation datasets. These approaches provide HiMAT with a robust toolkit for assessing which products should be used as forcing datasets for land surface modeling occurring later in the project.

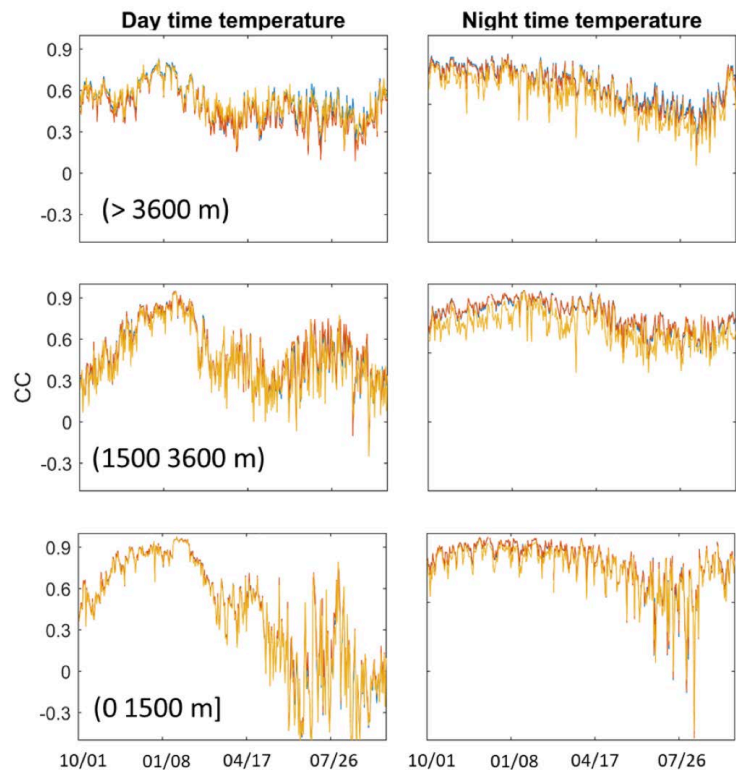
**Yun Qian** [Pacific Northwest National Laboratory (PNNL)] presented an intercomparison of ten precipitation datasets derived from ground or satellite observations over the HMA region for the 2014 water year. The resolution of the precipitation datasets varied spatially (between 0.25° and 1°) and temporally (hourly-to-monthly). Qian noted that the sparsely available gauge network over the western Tibetan Plateau region in China limits the ability to conduct orographic corrections. He also pointed out that the spatial correlations between precipitation datasets have to be considered. Qian then proposed a few ideas on how to account for the uncertainties in observational precipitation data.

**Yiwen Mei** [George Mason University (GMU)] presented his latest downscaling scheme for atmospheric variables (e.g., air temperature, pressure, specific humidity, incident longwave radiation, total precipitation, convective rainfall, large-scale rainfall, and snowfall) in HMA based on a dynamic lapse rate. He explained that the new method improves over the previous version, which downscaled cumulative rather than hourly rainfall based on seasonal Normalized Difference Vegetation Index (NDVI) resulting in static rainfall patterns. Mei's downscaling technique demonstrated good correlation between surface temperatures calculated using MERRA and land surface temperatures measured by the Moderate Resolution Imaging Spectroradiometer (MODIS).<sup>4</sup> The results—shown in the **Figure** above for water year 2008<sup>5</sup>—indicate that the downscaled air temperature product shows better consistency with the night time MODIS land surface temperature than the day time one. This could be due to the various processes involved

<sup>4</sup> MODIS flies on NASA's Terra and Aqua platforms.

<sup>5</sup> The team has chosen water years 2008 and 2014 for initial data comparisons across HiMAT; results from 2014 are similar to those obtained in 2008.

in the regulation of the land surface and air temperature during the day (e.g., solar insolation, sun angle, cloud cover, surface shading and advection). At night, the variation of the two temperatures mostly follow the emissivity properties of the surface. High variability of the correlation coefficient (CC) values can also be observed during the early June to September period (which is monsoon season in the HiMAT region, with prevalent cloudy conditions) mainly due to lack of coverage of the MODIS land surface temperature product during those times.



**Figure.** Correlation coefficient (CC, shown on y-axis in graphs) between downscaled air temperature and MODIS land surface temperature for both day [left column] and night [right column] during water year 2008 at three different elevation ranges [rows].

**Figure credit:** Yiwen Mei [George Mason University]

**Dalia Kirschbaum** [GSFC] presented her research on landslide triggering across HMA. She emphasized that it is important to capture extreme events correctly in model runs, because landslides are caused by extreme weather rather than the average conditions. She presented her evaluation of extreme precipitation in several analyses, including Tropical Rainfall Measuring Mission (TRMM) Multisatellite Precipitation Analysis [TMPA], MERRA-2 downscaled, and National Oceanic and Atmospheric Administration's (NOAA's) Geophysical Fluid Dynamics Laboratory (GFDL)

general circulation model (GCM) between 2001 and 2015. By combining these datasets with information on the ranges of rainfall in which the majority of landslides occur, Kirschbaum's team will be able to provide more accurate predictions of landslide events.

**Sarah Kapnick** [GFDL] presented results using Atmospheric Model, Version 4 (AM4) of the GFDL GCM, trying to answer the question: *Can different ensemble members from 1980–2015 better help to reproduce precipitation statistics over HMA?* She emphasized that they have simulated hundreds of model years for assessing extreme precipitation events. The long time span of these GCM simulations is particularly important with respect to HiMAT efforts aimed at assessing the magnitude and risk of extreme precipitation events.

**Stephen Nicholls** [GSFC] presented his results on the regional climate modeling of HMA using the Coupled Ocean-Atmosphere-Wave-Sedimentation Transport Modeling System (COAWST)—described at <https://woodshole.er.usgs.gov/operations/modeling/COAWST>. He explained that ocean and atmosphere coupling provides better constraints on the climate model because they resolve two-way ocean–atmosphere feedbacks. Nicholls described the different microphysics parameterizations tested against measurements of precipitation from TRMM using a *threat score*, which indicates the accuracy of precipitation coverage. He also added that the coupled ocean–atmosphere models have a high bias in orographic precipitation.

**Kyu-Myong Kim** [GSFC] presented updates on his team's Global Earth Observing System, Version 5 (GEOS-5) model experiments. He described how they conducted a series of five ensemble experiments, with the objective of examining the relative roles of absorbing aerosols in atmospheric heating and snow albedo, and their impacts on snowmelt over the Tibetan Plateau. Kim showed that the South Asian monsoon had near-normal rainfall in 2008, with anomalously high aerosol loading. These conditions corresponded with a La Niña event in the equatorial Pacific Ocean, and work is ongoing to assess connections between aerosol loadings and these various forcing factors.

### Session B: Validation

A central challenge in studying precipitation in the HMA region is that there are so few ground observations with which to validate model output or ensemble precipitation estimates from remotely sensed observations. While the team continues to assemble as many ground measurements as possible (see Session C), they are also exploring methods that enable the team to assess outliers and provide statistical measures of potential bias in the data.

**William Christensen** [BYU] presented the Latent Factor Analysis (LFA) as a method for defining consensus among modeling results and reanalysis products. Instead of taking an arithmetic average, LFA generates a linear weighted sum using confirmatory factor analysis, distributing the weights based on the correlation of observations or models. He explained that if all observations use the same satellite or gauge data for input, biases have to be removed using independent data, or *known truth*. Removing the known truth from the results and then applying the LFA can reduce the impact of having similar biases in results. Christensen also showed another approach, based on Gaussian processes, as a way to fill in the spatial and temporal data gaps with a given smoothness factor. This process can be used to combine TRMM (or similar) data with even sparsely available rain gauge data to provide a correct precipitation dataset with uncertainty estimates over space and time.

**Paul Houser** [GMU] explained that merging or averaging operations tend to diminish extremes. He suggested that bias correction and downscaling might be better than Bayesian merging at leaving the extreme values in model results intact. Houser proposed a test study using available ground-truth data (either in HMA or in the U.S.), to get an idea of the biases in model results.

**Viviana Maggioni** [GMU] discussed the necessity of consensus among models beyond average precipitation amounts. An important point is to consider the ratio of rain versus no-rain cases, which allows generating a *confusion matrix* that provides information on false-positives, missed precipitation, and correct detection. She also pointed out that precipitation estimates (e.g., TMPA and CMORPH<sup>6</sup>) have different behaviors in false-positives.

**Sujay Kumar** [GSFC] reviewed his overall approach to model validation, starting with initial simulations over a subdomain of the HMA, in this case the Indus River Basin. These initial simulations allow us to assess overall behavior of various land surface models. He then described how the validation and assimilation tools embedded in the NASA Land Information System could be used to investigate model performance in greater detail. Kumar acknowledged that the duration of the dataset over the Indus River Basin is still fairly short, and that a longer time series would allow for better analysis. He added that detailed knowledge of the total runoff in observed locations is of utmost importance to answer the science questions.

<sup>6</sup>CMORPH stands for NOAA's National Center for Environmental Prediction's (NCEP) Climate Prediction Center [CPC] Morphing technique for the production of global precipitation estimates.

### Session C: Data Access and Computational Methods

In this session the group discussed opportunities and challenges in acquiring data, standardizing model output formats, and expanding shared NASA-based computing resources to enhance potential for cross-team collaboration.

**Anthony Arendt** [University of Washington] led a discussion of potential sources for ground data. In addition to widely available sources such as the Global Historical Climatology Network (<https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets/global-historical-climatology-network-ghcn>) and Weather Underground station data (<https://www.wunderground.com>), data are also available from the Chinese Meteorological Administration; the Pakistan Water and Power Development Authority; the Pakistan Meteorological Department; and the Department of Hydrology and Meteorology in Nepal. Arendt reviewed a series of actions currently in progress to purchase ground station data from these sources.

Arendt then provided an overview of resources available to HiMAT on NASA's Advanced Data Analytics Platform (ADAPT, see <https://www.nccs.nasa.gov/services/adapt>). **Thomas Stanley** [GSFC] described his challenges in analyzing large gridded datasets on ADAPT. Arendt shared several Python tools that are available to handle larger-than-memory problems with utilities such as Xarray and Dask. Regarding data sharing, Arendt recommended that climate modeling results be stored on ADAPT to facilitate analysis of datasets across the team. He encouraged the group to share analysis codes using version control and the HiMAT GitHub repository. **Yun Qian** [PNNL] suggested use of NetCDF for a common

data format, which was accepted by the team. The group affirmed the choice initially made at the November 2016 HiMAT meeting to use water years 2008 and 2014 for initial comparisons.

**Batu Osmanoglu** [GSFC] led a discussion on standardization of model output formats. He stated that routines that read several datasets and model outputs that provide a standard output format would be beneficial when ingesting data from several groups for analysis. He suggested that the model comparison should be separated into two steps: the first should focus on direct comparison of climate model outputs (e.g., precipitation), while the second should focus on derived parameters (e.g., total runoff) using land assimilation models driven by these climate models.

### Closing

The team closed the meeting by laying out a plan to collaborate on the preparation of several research papers to submit for publication. Research topics will include the intercomparison of observational datasets, global and regional modeling, and resulting variations in land-assimilation models. Tasks related to the progress of these collaborative papers will be tracked as separate "Projects" on the HiMAT GitHub repository (<https://github.com/NASA-Planetary-Science/HiMAT/projects>).

After intense deliberation on precipitation-related topics, the team ended the meeting with commitments to continuing existing and developing additional close collaborations and assignments of subtask leaders for the model and data intercomparison papers. **Anthony Arendt** agreed to organize follow-on biweekly meetings on precipitation, to help facilitate further collaboration. ■

# NASA's Longest Running Survey of Ice Shattered Records in 2017

Maria-José Viñas, NASA's Goddard Space Flight Center, Earth Science News Team, maria-jose.vinasgarcia@nasa.gov

**EDITOR'S NOTE:** This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

Last year was a record-breaking one for Operation IceBridge, NASA's aerial survey of the state of polar ice.<sup>1</sup> For the first time in its nine-year history, the mission, which aims to close the gap between two NASA satellite campaigns that study changes in the height of polar ice, carried out seven field campaigns in the Arctic and Antarctic in a single year.<sup>2</sup> In total, the IceBridge scientists and instruments flew over 214,000 miles (-344,400 km), the equivalent of orbiting the Earth 8.6 times at the equator.

"A big highlight for 2017 is how we increased our reach with our new bases of operations and additional campaigns," said **Nathan Kurtz** [NASA's Goddard Space Flight Center (GSFC)—*Operation IceBridge Project Scientist*]. "In the Arctic, we flew out of Svalbard, Norway, for the first time, expanding our coverage of the Eastern Arctic Ocean. And with our two Antarctic aircraft campaigns from Argentina and East Antarctica, we've flown over a large area of the Antarctic continent."

The expanding sets of measurements collected by IceBridge will continue to be invaluable for researchers to advance their understanding of how the Greenland and Antarctic ice sheets are contributing to sea level rise and how the changing polar sea ice impacts weather and climate. For example, in 2017, scientists worldwide published studies that used IceBridge data to look at ways to improve forecasts of sea ice conditions and to use satellites to map the depth of the layer of snow on top of sea ice, a key measurement in determining sea ice volume.

Regarding research on ice sheets and glaciers, 2017 saw further integration of Operation IceBridge's ice height measurements into decades-long records that combine airborne and satellite data, as well as the use of combinations of datasets from multiple IceBridge instruments, including its radars and laser altimeter, into products such as an improved map of the bedrock underneath Greenland's ice sheet, and studies that looked at the evolution of glaciers.

<sup>1</sup> The mission of Operation IceBridge, NASA's longest-running airborne mission to monitor polar ice, is to collect data on changing polar land and sea ice and maintain continuity of measurements between NASA's Ice, Clouds, and land Elevation satellite (ICESat) and ICESat-2 missions.

<sup>2</sup> From the South Pole to Greenland, from Alaska's glaciers to Svalbard, NASA's Operation IceBridge covered the icy regions of our planet in 2017 with a record seven separate field campaigns. To see a visual summary of all the campaigns, visit <https://www.nasa.gov/feature/goddard/2018/big-year-for-icebridge>.

Since 2009, IceBridge has carried at least two major campaigns per year, in the Arctic and Antarctica, plus two smaller yearly sets of flights in Alaska. In 2017 the team overcame several logistical challenges in order to nearly double the number of campaigns flown compared to previous years.

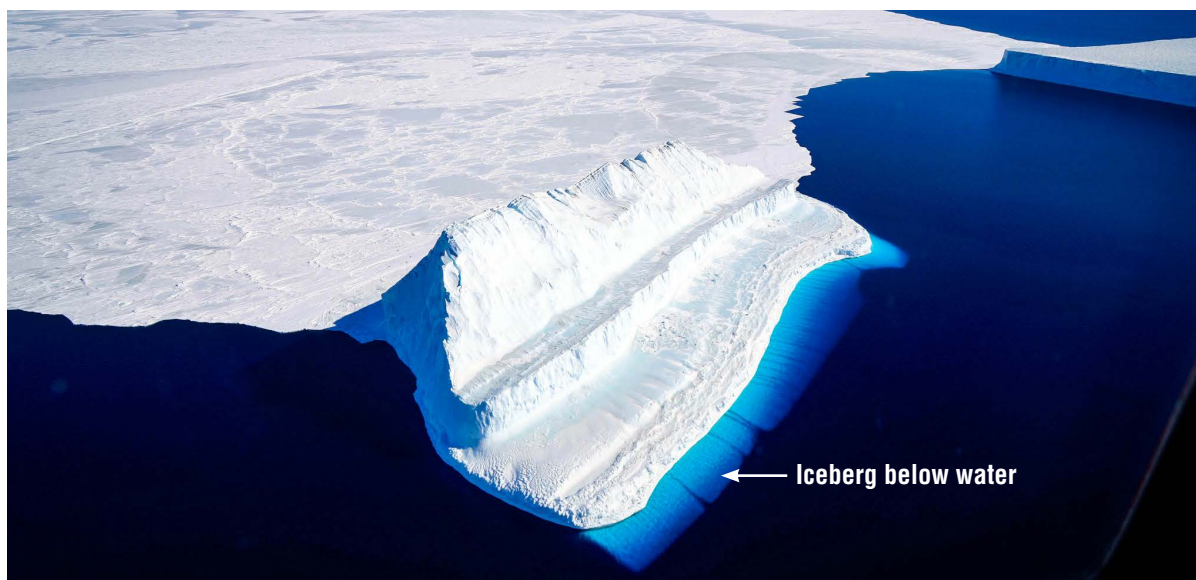
"Working in new locations and with different airplanes as we did this year always presents a challenge, but we took them on in order to continue expanding our knowledge of some little-explored areas of the Arctic and Antarctic," Kurtz said.

The first IceBridge campaign of the year was in the Arctic springtime. From March 9 until May 12, 2017, the mission carried a total of 40 flights (14 over sea ice and 26 over land ice) from four sites: Thule Air Base and Kangerlussuaq in Greenland, Fairbanks in Alaska, and the Norwegian archipelago of Svalbard. This was the first time IceBridge explored the Eurasian half of the Arctic Basin to collect data on sea ice and snow in a scarcely measured section of the Arctic Ocean and surrounding seas, along with surveys of a few glaciers in the Svalbard archipelago.



Operation IceBridge flew over a new crack in Petermann Glacier, one of the largest and fastest-changing glaciers in Greenland, on April 14, 2017, just a few days after the rift was detected in satellite imagery.

**Credits:** NASA/Gary Hoffmann



Iceberg in McMurdo Sound. The part of the iceberg below water appears bluest primarily due to blue light from the water in the Sound. **Photo credit:** Chris Larsen/UAF

The airborne mission also collaborated with international teams in collecting and comparing measurements of snow and ice. Partners included the CRYOsat Validation Experiment (CryoVEx)—a campaign to validate data collected by the European Space Agency’s (ESA) CryoSat-2 satellite; a group of European adventurers taking snow depth data while en route to the North Pole; ESA’s Copernicus Sentinel-3A satellite; and a GPS survey near Summit Station, Greenland, designed to help with instrument calibration on upcoming missions, e.g., the Ice, Cloud, and land Elevation Satellite-2 (ICESat-2).

Next, the IceBridge scientists performed four sets of flights in the Arctic during the summer to measure how the melt season impacted Arctic sea and land ice. In July, the mission carried six surveys out of Thule Air Base, in northwest Greenland, focusing on the older and thicker sea ice cover north of Greenland and in the Canadian Archipelago. IceBridge also completed an experiment to determine how well the laser instrument could measure the depth of the aquamarine lakes of meltwater that form on the surface of the Greenland Ice Sheet and Arctic sea ice every summer. Preliminary results indicate that the laser could penetrate more than 30 ft (~9 m) through these lakes, a first step to gauge the depth of these ponds.

The second summer Arctic campaign, flown between August 25 and September 20, 2017, was launched from Kangerlussuaq, in central Greenland, and replicated land ice surveys that IceBridge had carried the previous spring. A total of 15 flights measured how much ice had melted since spring.

Meanwhile, in Alaska, a companion campaign that regularly monitors the state of the Alaskan mountain glaciers completed two sets of flights in May and August. Led by

**Chris Larsen** [University of Alaska, Fairbanks], Operation IceBridge-Alaska carried a total of 10 aerial surveys.

“The main focus was repeated lines for laser altimetry, but we also expanded our radar coverage on the Bering and Malaspina glaciers,” Larsen said. “A highlight of the missions was flying the Harding and Sargent icefields on the Kenai Peninsula. Other areas included the Fairweather Range in Glacier Bay National Park, and the eastern Alaska Range.”

The last feat of 2017 for IceBridge was launching two consecutive sets of Antarctic flights from South America and Antarctica. The first Antarctic campaign, carried out from October 29 to November 25, 2017, from Ushuaia, Argentina, comprised 11 science flights over the Antarctic Peninsula and Weddell Sea that included gravity surveys of the Larsen C and Venable Ice Shelves, plus two flights under the tracks of the German TanDEM-X satellite to explore whether scientists can use the radar data from the spacecraft to detect a band of older and thicker sea ice that may exist near the northern edge of the ring of sea ice around Antarctica.

Finally, IceBridge scientists and instruments deployed to McMurdo Station, Antarctica. From there, they completed 16 survey flights between November 28 and December 18, 2017—see photo above.

“Our McMurdo campaign exceeded all expectations,” said **Joe MacGregor** [GSFC—*Operation IceBridge Deputy Project Scientist*]. “We covered lots of ground around the South Pole, the Transantarctic Mountains, the Ross Ice Shelf, and Victoria Land. We surveyed all our highest priority targets and then some.”

For more about Operation IceBridge and to follow future campaigns, visit <http://www.nasa.gov/icebridge>. ■



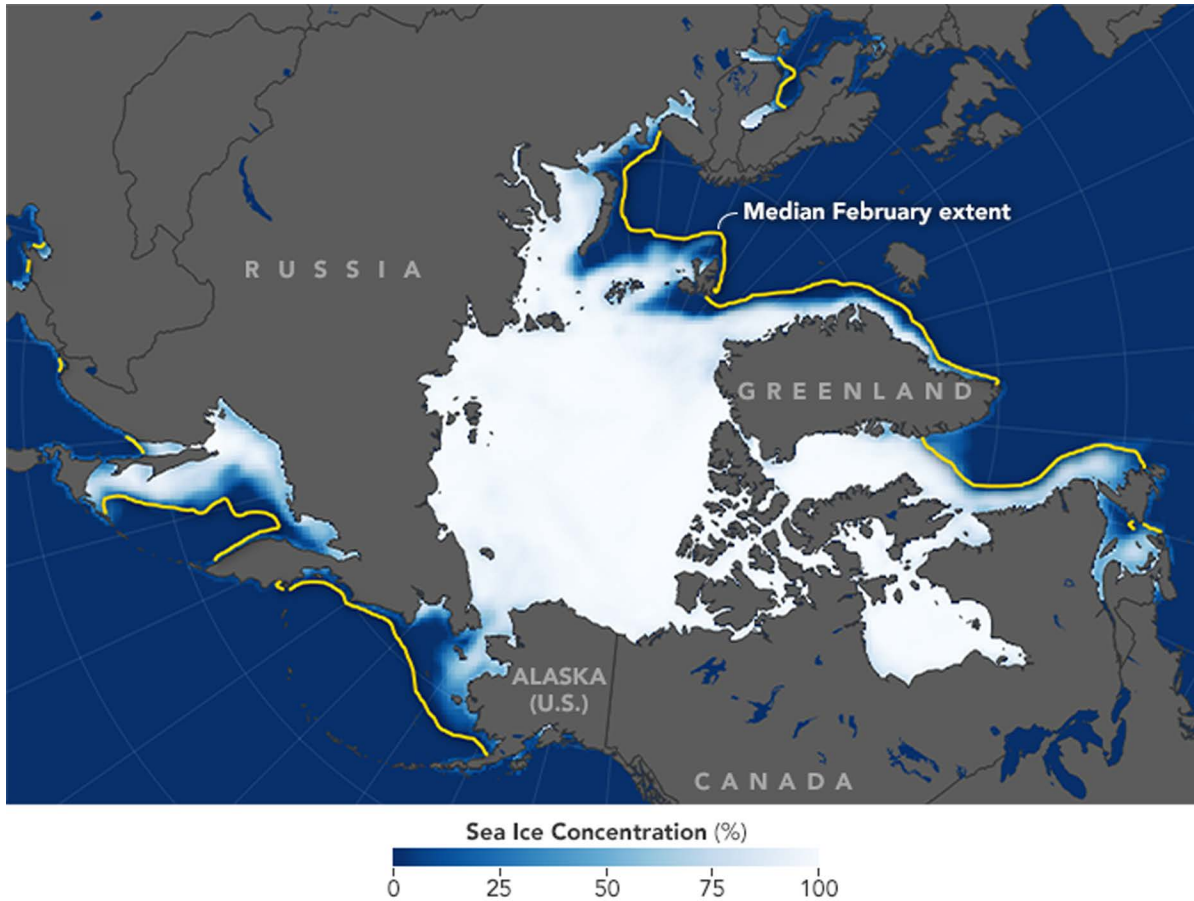
# Low Sea Ice Amid Arctic Warming

Kathryn Hansen, NASA's Earth Observatory, [kathryn.h.hansen@nasa.gov](mailto:kathryn.h.hansen@nasa.gov)

Maria-José Viñas, NASA's Goddard Space Flight Center, Earth Science News Team, [maria-jose.vinasgarcia@nasa.gov](mailto:maria-jose.vinasgarcia@nasa.gov)

in the news

**EDITOR'S NOTE:** The following image and text originally appeared as an Image of the Day on the *Earth Observatory* website. It has been modified slightly to match the style used in *The Earth Observer*. Color versions of the graphics appear at <https://earthobservatory.nasa.gov/IOTD/view.php?id=91817>



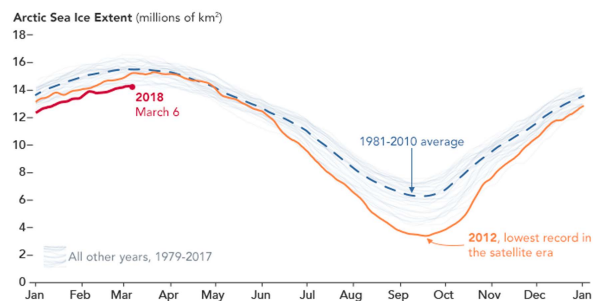
**Figure 1.** Average concentration of Arctic sea ice in February 2018. **Credit:** NASA's Earth Observatory

Arctic sea ice reaches its maximum extent each March, following months of growth during usually frigid and dark autumn and winter. The date of maximum extent for winter 2018 has yet to be determined, but in February 2018, the average ice extent was the lowest of any February on record.

**Figure 1** shows the average concentration of Arctic sea ice in February 2018. Opaque white areas indicate the greatest concentration, and dark gray areas are open water. All icy areas pictured here had an ice concentration of at least 15% (the minimum at which space-based measurements give a reliable measurement), and cover a total area that scientists refer to as the “ice extent.”

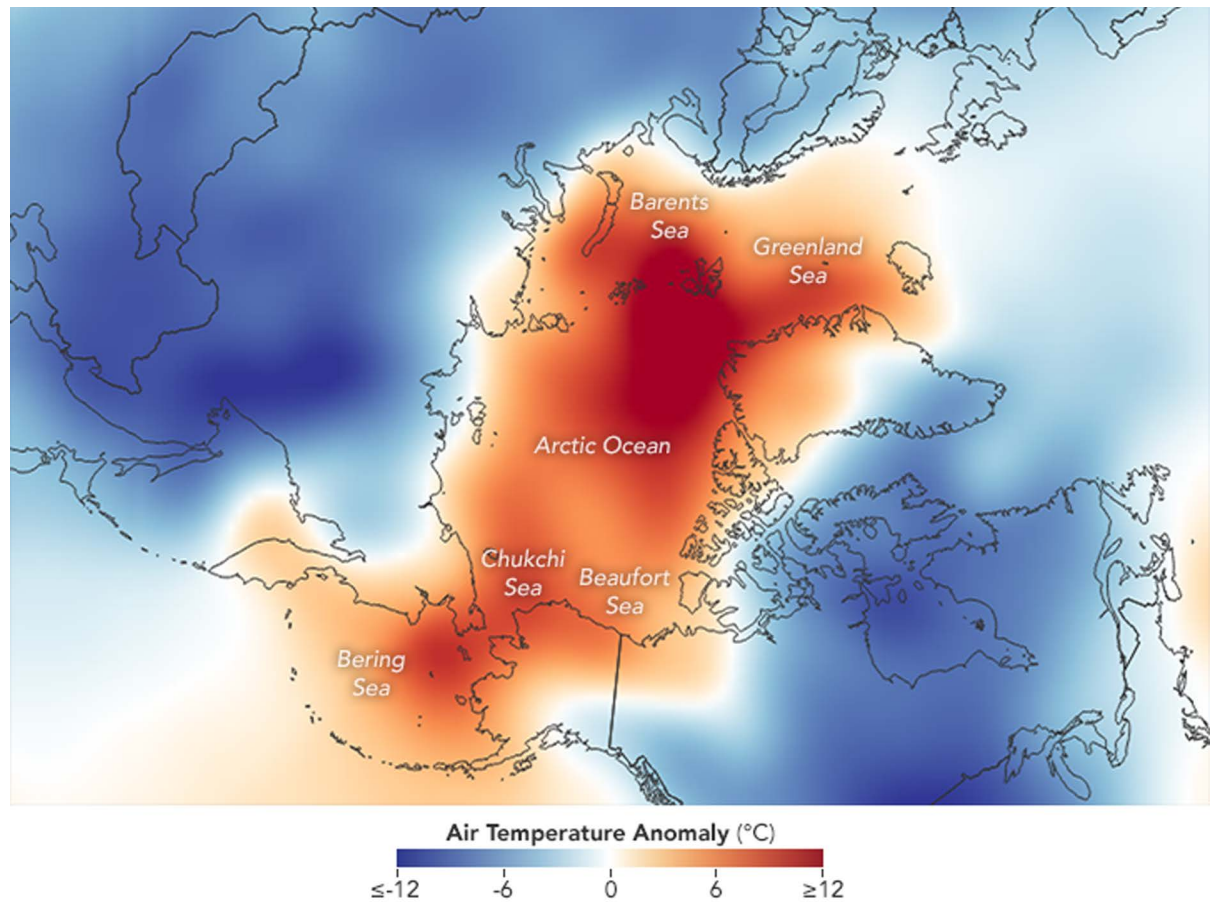
The February extent averaged 13.95 million km<sup>2</sup> (5.39 million mi<sup>2</sup>), according to the National Snow & Ice Data Center.<sup>1</sup> **Figure 2** shows how Arctic sea ice growth this year compares with all years since 1979.

<sup>1</sup> That is 1.35 km<sup>2</sup> (521,240 mi<sup>2</sup>) below the 1981–2010 average for February.



**Figure 2.** Arctic sea ice growth in 2018 compared to all years since 1979. **Credit:** NASA's Earth Observatory

The lackluster ice growth—and the decline in areas such as the Bering and Chukchi seas—was influenced by a so-called *winter warming event*. Low pressure off of Greenland and high pressure over Europe helped move warm air masses—and possibly some warm water—from the North Atlantic into the Arctic Ocean. A similar scenario also played out on the Pacific side: low- and



**Figure 3.** Air temperature anomalies for February 2018. Red depicts areas that were hotter than average; blue were colder than average. **Credit:** NASA's Earth Observatory

high-pressure systems set up in such a way as to move warm air and water from the North Pacific through the Bering Strait.

“We have seen winter warming events before, but they’re becoming more frequent and more intense,” said **Alek Petty** [NASA's Goddard Space Flight Center].

Areas of unusual warmth are visible in **Figure 3**, which shows air temperature anomalies for February 2018. Dark shades depict areas that were hotter than average; lighter shades were colder than average. At times, the North Pole saw temperatures climb above freezing, soaring 20–30 °C (36–54 °F) above the norm.<sup>2</sup>

<sup>2</sup> See related News story on page 31.

Notice the area north of Greenland. This is the site of another exceptional event this winter: open water instead of sea ice cover. Without the ice cover here, heat is being released from the ocean to the atmosphere, making the sea ice more vulnerable to further melting.

“This is a region where we have the thickest multi-year sea ice and expect it to not be mobile, to be resilient,” Petty said. “But now this ice is moving pretty quickly, pushed by strong southerly winds and probably affected by the warm temperatures, too.”

NASA's Operation IceBridge—an airborne mission to map polar ice—will make measurements in the area when annual science flights resume in late March. ■

## Farewell to a Pioneering Pollution Sensor

Carol Rasmussen, NASA/Jet Propulsion Laboratory, [carol.m.rasmussen@jpl.nasa.gov](mailto:carol.m.rasmussen@jpl.nasa.gov)

**EDITOR'S NOTE:** This article is taken from *nasa.gov*. While it has been modified slightly to match the style used in *The Earth Observer*, the intent is to reprint it with its original form largely intact.

On January 31, 2018, NASA ended the Tropospheric Emission Spectrometer's (TES) almost 14-year career of discovery. Launched in 2004 on NASA's Aura spacecraft, TES was the first instrument designed to monitor ozone in the lowest layers of the atmosphere directly from space—see **Figure**. Its high-resolution observations led to new measurements of atmospheric gases that have altered our understanding of the Earth system.

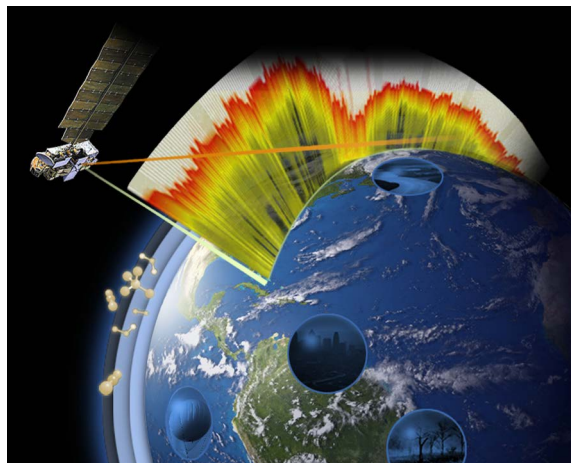
TES was planned for a five-year mission but far outlasted that term. A mechanical arm on the instrument began stalling intermittently in 2010, affecting TES's ability to collect data continuously. The TES operations team adapted by operating the instrument to maximize science operations over time, attempting to extend the dataset as long as possible. However, the stalling increased to the point that TES lost operations about half of last year. The data gaps hampered the use of TES data for research, leading to NASA's decision to decommission the instrument. It will remain on the Aura satellite, receiving enough power to keep it from getting so cold it might break and affect the two remaining functioning instruments.

"The fact that the instrument lasted as long as it did is a testament to the tenacity of the instrument teams responsible for designing, building, and operating the instrument," said **Kevin Bowman** [NASA/Jet Propulsion Laboratory (JPL)—*TES Principal Investigator (PI)*].

### A True Earth System Sounder

TES was originally conceived to measure ozone in the troposphere, the layer of atmosphere between the surface and the altitude where intercontinental jets fly, using high-spectral-resolution observations of thermal infrared radiation. However, TES cast a wider net, capturing signatures of a broad array of other atmospheric gases as well as ozone. That flexibility allowed the instrument to contribute to a wide range of studies—not only atmospheric chemistry and the impacts of climate change, but studies of the cycles of water, nitrogen, and carbon.

One of the surprises of the mission was the measurement of *heavy water*—water molecules composed of deuterium, an isotope of hydrogen that has more neutrons than normal hydrogen. The ratio of deuterium to "normal" water in water vapor gives clues to the vapor's history—i.e., how it evaporated and fell as precipitation in the past—which in turn helps scientists discern what controls the amount in the atmosphere.



**Figure.** TES collected spectral "signatures," illustrated here, of ozone and other gases in the lower atmosphere. **Image credit:** NASA

Heavy water data have led to fundamental advances in our understanding of the water cycle that were not possible before, e.g., how tropical thunderstorms keep the troposphere hydrated, how much water in the atmosphere is evaporated from plants and soil as compared to surface water, and how water "exhaled" from southern Amazon vegetation jump-starts the rainforest's rainy season. **John Worden** [JPL], the scientist who pioneered this measurement technique, said: "It's become one of the most important applications of TES. It gives us a unique window into Earth's hydrological cycle."

While the nitrogen cycle isn't as well measured or understood as the water cycle, nitrogen makes up 78% of the atmosphere, and its conversion to other chemical compounds is essential to life. TES demonstrated the first space measurement of a key nitrogen compound—ammonia. This compound is a widely used fertilizer for agriculture in solid form, but as a gas, it reacts with other compounds in the atmosphere to form harmful pollutants.

Another nitrogen compound, peroxyacetyl nitrate (PAN), can be lofted into the troposphere from fires and human emissions. Largely invisible in data collected at ground level, this pollutant can travel great distances before it settles back to the surface, where it can form ozone. TES showed how PAN varied globally, including how fires influenced its distribution.

"TES really paved the way in our global understanding of both PAN and [ammonia], two keystone species in the atmospheric nitrogen cycle," said **Emily Fischer** [Colorado State University, Fort Collins, Department of Atmospheric Science].

### The Three Faces of Ozone

Ozone, a gas with both natural and human sources, is known for its multiple “personalities.” In the stratosphere, ozone is benign, protecting Earth from incoming ultraviolet radiation. In the troposphere, it has two distinct harmful functions, depending on altitude. At ground level it’s a pollutant that hurts living plants and animals, including humans. Higher in the troposphere, it’s the third most important human-produced greenhouse gas, trapping outgoing thermal radiation and warming the atmosphere.

TES data, in conjunction with data from other instruments on Aura, were used to disentangle these personalities, leading to a significantly better understanding of ozone and its impact on human health, climate, and other parts of the Earth system.

Air currents in the mid- to upper-troposphere carry ozone not only across continents but across the ocean to other continents. A 2015 study using TES measurements found that the U.S. West Coast’s tropospheric ozone levels were higher than expected, given decreased U.S. emissions, partly because of ozone that blew in across the Pacific Ocean from China.<sup>1</sup> The rapid growth in Asian emissions of *precursor gases*—gases that interact to create ozone, including carbon monoxide and nitrogen dioxide—changed the global landscape of ozone.

“TES has borne witness to dramatic changes in which the gases that create ozone are produced. TES’s remarkably stable measurements and ability to resolve the layers of the troposphere allowed us to separate natural changes from those driven by human activities,” said **Jessica Neu** [JPL], co-author of the 2015 study.

Regional changes in emissions of ozone precursor gases alter not only the amount of ozone in the troposphere, but its efficiency as a greenhouse gas. Scientists used TES measurements of ozone’s greenhouse effect, combined with chemical weather models, to quantify how the global patterns of these emissions have altered climate.

“In order to both improve air quality and mitigate climate change, we need to understand how human pollutant emissions affect climate at the scales in which policies are enacted [that is, at the scale of a city, state, or country]. TES data paved the way for how satellites could play a central role,” said **Daven Henze** [University of Colorado at Boulder, Department of Mechanical Engineering].

### A Pathfinder Mission

“TES was a pioneer, collecting a whole new set of measurements with new techniques, which are now

being used by a new generation of instruments,” Bowman said. Its successor instruments are used for both atmospheric monitoring and weather forecasting. Among them are the National Oceanic and Atmospheric Administration (NOAA)’s Cross-track Infrared Sounder (CrIS) instruments on the NOAA-NASA Suomi National Polar-orbiting Partnership (NPP) satellite and NOAA-20, and the Infrared Atmospheric Sounding Interferometer (IASI) series, developed by the French space agency in partnership with the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

**Cathy Clerbaux** [Centre National de la Recherche Scientifique], who is the leading scientist on the IASI series, said, “TES’s influence on later missions like ours was very important. TES demonstrated the possibility of deriving the concentration of atmospheric gases by using interferometry to observe their molecular properties. Although similar instruments existed to sound the upper atmosphere, TES was special in allowing measurements nearer the surface, where pollution lies. The scientific results obtained with IASI greatly benefited from the close collaboration we developed with the TES scientists.”

TES scientists have been pioneers in another way: by combining the instrument’s measurements with those of other instruments to produce enhanced datasets, revealing more than either original set of observations. For example, combining the Ozone Monitoring Instrument on Aura’s measurements in ultraviolet wavelengths with TES’s thermal infrared measurements gives a dataset with enhanced sensitivity to air pollutants near the surface.

The team is now applying that capability to measurements by other instrument pairs—e.g., enhanced carbon monoxide from CrIS with carbon monoxide and other measurements from the Tropospheric Monitoring Instrument (TROPOMI) on the European Space Agency’s Copernicus Sentinel-5 Precursor satellite.

“The application of the TES algorithms to CrIS and TROPOMI data will continue the 18-year record of unique near-surface carbon monoxide measurements from the Measurement of Pollution in the Troposphere (MOPITT) instrument on Terra into the next decade,” said **Helen Worden** [National Center for Atmospheric Research—MOPITT PI and a *TES Science Team Member*].

These new techniques developed for TES along with broad applications throughout the Earth System assure that the mission’s legacy will continue long after TES’s final farewell. ■

<sup>1</sup>To learn more, see <https://www.jpl.nasa.gov/news/news.php?feature=4685>.



## NASA Earth Science in the News

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

**Tiny Satellites to Make Crucial Arctic Climate Measurements for the First Time**, March 9, *earthr.com*. The Arctic is warming about twice as fast as the rest of the planet, but major questions remain, including how quickly sea ice will retreat, and how much of Greenland's ice will slide into the sea, over the decades to come. A new NASA-led experiment could help deliver answers, by measuring a key component of the Arctic's energy balance from space for the very first time. In the early 2020s, NASA will launch the Polar Radiant Energy in the Far Infrared Experiment (PREFIRE),<sup>1</sup> a pair of lightweight satellites carrying instruments capable of measuring far infrared emissions from Earth's poles. **Tristan L'Ecuyer**, [University of Wisconsin, Madison—*PREFIRE Principal Investigator*] called the far infrared a “very important region of the energy exchange... that governs the Arctic climate. This is a completely unique measurement we need.” **Tom Wagner** [NASA Headquarters—*Program Scientist for the Cryosphere*] was similarly enthused about the experiment's potential. “They may really start to understand what the heck is going on with energy balance in the Arctic and why it's heating faster than the rest of the planet.”

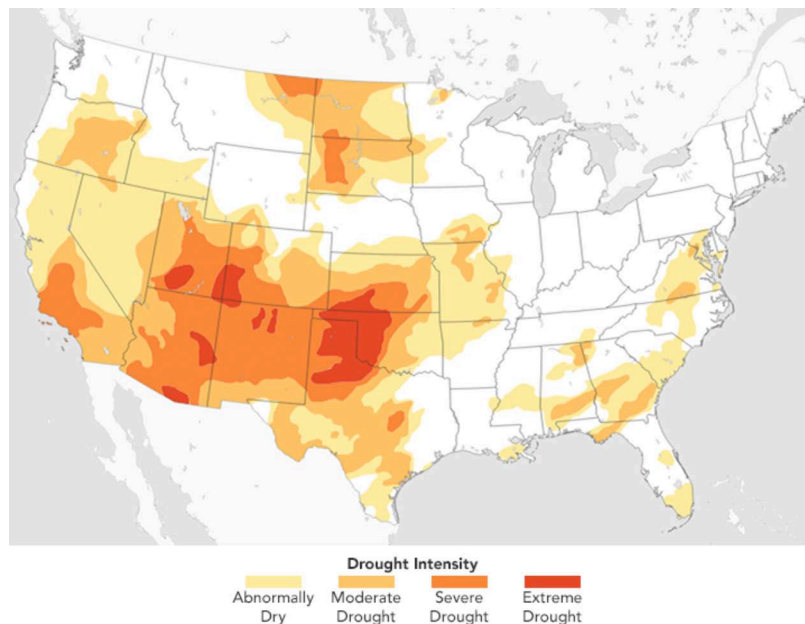
**Permafrost Thaw Could Spew Greenhouse Gases Within Decades**, March 7, *cnet.com*.

A surprising NASA study indicates that the coldest areas of Arctic permafrost may start to thaw and unleash their reservoirs of carbon within mere decades. Permafrost isn't necessarily permanent. A new NASA study looked at the frozen soil layer in the coldest reaches of the northern Arctic and found it could “thaw enough to become a permanent source of carbon to the atmosphere in this century.” The Arctic permafrost, located beneath the topsoil layer, has remained frozen for long stretches of time, but it holds a stash of organic materials, including leaves. When it thaws,

<sup>1</sup>PREFIRE and Earth Surface Mineral Dust Source Investigation (EMIT) are the two instruments that were competitively selected from 14 proposals considered under NASA's fourth Earth Venture Instrument opportunity. Earth Venture investigations are small, targeted science investigations that complement NASA's larger missions.

that material breaks down and releases methane and carbon dioxide—greenhouse gases. These gases, which are also generated by human activities, can contribute to global warming. **Nicholas Parazoo** [NASA/Jet Propulsion Laboratory] led the study, which involved running model simulations that calculated changes in carbon emissions, plant growth, and permafrost due to a warming climate. A paper describing the work has been published in the journal *Cryosphere*, and concludes that “Over the course of the model simulations, northern permafrost lost about five times more carbon per century than southern permafrost.”

**Drought Has Returned to the U.S. This Winter**, NASA Map Shows, *March 5*, *weather.com*. Drought conditions have returned to much of the U.S. Desert Southwest and southern Plains due, in part, to a dry winter that left the land parched in several states. Using data from the U.S. National Drought Monitor, NASA compiled a map that shows the areas of the country that have fallen back into some of the worst drought categories just nine months after 95% of the nation was drought-free—see **Figure**. The map, using data acquired February 27, 2018, shows extreme drought taking over parts of Texas and the Desert Southwest,



**Figure.** This map was compiled from data provided by the U.S. National Drought Monitor, a partnership of U.S. Department of Agriculture, the National Oceanic and Atmospheric Administration, and the University of Nebraska-Lincoln. It depicts areas of drought on February 27, 2018, in progressive shades yellow to orange. The index used is based on measurements of climate, soil, and water conditions from more than 350 federal, state, and local observers. **Credit:** NASA's Earth Observatory

with moderate or severe drought seen in the Southeast, Northern Plains and parts of California. As an example, from October 13 to February 16, 2018—125 consecutive days—Amarillo, TX, didn't record a single day with any rainfall.

**A Supercolony of 1.5 Million Penguins Went Unnoticed Until Now**, March 3, *qz.com*. The story of how scientists discovered a massive “supercolony” of Adélie penguins in Antarctica—which they detailed in a study published Friday (March 2) in *Scientific Reports*—begins in 2014, with NASA satellite imagery. **Heather Lynch** [Stony Brook University] and **Mathew Schwaller** [NASA's Goddard Space Flight Center] spotted guano stains in images of the Danger Islands, off the northern tip of the continent. Where there are penguin droppings, there are most certainly penguins, and the stains, visible from space, suggested there were a large number of them. But only a trip to the rocky, remote chain of islands could confirm the suspicion. The duo teamed with ecologists from Woods Hole Oceanographic Institution and other universities in the U.S. and U.K. for an expedition in 2015. They found penguins nesting at the landing site, and beyond that a colony of an estimated 1.5 million Adélie penguins, a “hidden metropolis,” writes Science Alert. This meant there were more Adélie penguins in the Danger Islands than in the rest of the Antarctica Peninsula combined, as the researchers report in the study. They called the area “a major hotspot of Adélie penguin abundance.”

**New NASA Study Finds Dramatic Acceleration in Sea Level Rise**, March 2, *space.com*. According to new research, global sea level isn't rising steadily—it's getting faster every year. The findings, which came from an analysis of 25 years' worth of satellite data, are bad news for all low-lying regions threatened by the encroaching ocean: It may rise twice as high by 2100 than was previously estimated. The study, published on February 12, 2018, in the journal *Proceedings of the National Academy*

*of Sciences*, concluded that in the next 80 years, the sea level may rise by up to 26 in (66 cm) as a result of climate change, cutting much larger chunks from the coastal areas than previously estimated. “This is almost certainly a conservative estimate,” said **Steve Nerem** [University of Colorado Boulder], who led the NASA Sea Level Change team that conducted the study. “Our extrapolation assumes that sea level continues to change in the future as it has over the last 25 years,” Nerem said in a statement. “Given the large changes we are seeing in the ice sheets today, that's not likely.”

**NASA Launches Advanced Weather Satellite for Western U.S.**, March 2, *apnews.com*. NASA launched another of the world's most advanced weather satellites on March 1, 2018, this time to observe the Western U.S. The Geostationary Operational Environmental Satellite-S (GOES-S) satellite thundered toward orbit aboard an Atlas V rocket, slicing through a hazy late afternoon sky above NASA's Kennedy Space Flight Center in Cape Canaveral, FL. Dozens of meteorologists gathered for the launch, including TV crews from the Weather Channel and WeatherNation. GOES-S is the second of four planned satellite launches, an approximately \$11 billion “next-generation” effort by the National Oceanic and Atmospheric Administration that's already revolutionizing forecasting with astonishingly fast, crisp images of hurricanes, wildfires, floods, mudslides, and other natural calamities.

\* Please see related News story on this topic in this issue to learn more.

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

## EOS Science Calendar | Global Change Calendar

### April 25–27, 2018

AIRS Science Team Meeting,  
Pasadena, CA.

<http://airs.jpl.nasa.gov/events>

### May 15–17, 2018

CERES Science Team Meeting,  
Hampton, VA.

<https://ceres.larc.nasa.gov/science-team-meetings2.php>

### May 16–17, 2018

CLARREO Science Definition Team Meeting,  
Boulder, CO.

<https://clarreo.larc.nasa.gov/events.html>

### June 4–6, 2018

ASTER Science Team Meeting,  
Tokyo, Japan.

### September 24–29, 2018

OST Science Team Meeting,  
Ponta Delgada, Azores, Portugal.

<https://www.altimetry2018.org/>

[QuickEventWebsitePortal/25-years-of-progress-in-radar-altimetry-symposium/esa](https://www.altimetry2018.org/QuickEventWebsitePortal/25-years-of-progress-in-radar-altimetry-symposium/esa)

### May 20–24, 2018

2018 JpGU/AGU Joint Annual Meeting,  
Chiba, Japan.

[http://www.jpogu.org/meeting\\_e2018](http://www.jpogu.org/meeting_e2018)

### May 28–30, 2018

LCLUC International Regional Science Meeting,  
Quezon City, Philippines.

<http://lcluc.umd.edu/meetings/land-coverland-use-changes-lcluc-and-impacts-environment-southsoutheast-asia-international>

### June 3–8, 2018

Asia Oceania Geosciences Society,  
Honolulu, HI.

<http://www.asiaoceania.org/aogs2018/public.asp?page=home.htm>

### July 14–22, 2018

COSPAR 2018 Assembly,  
Pasadena, CA.

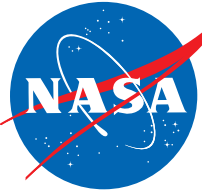
<http://cospar2018.org>

### September 24–29, 2018

25 Years of Progress in Radar Altimetry Symposium  
Ponta Delgada, Azores, Portugal.

<https://www.altimetry2018.org/>

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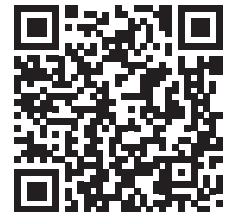
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Articles, contributions to the meeting calendar, and suggestions are welcomed. Contributions to the calendars should contain location, person to contact, telephone number, and e-mail address. Newsletter content is due on the weekday closest to the 1<sup>st</sup> of the month preceding the publication—e.g., December 1 for the January–February issue; February 1 for March–April, and so on.

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