Over Thirty Years Reporting on NASA's Earth Science Program

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The Editor's Corner

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ATTENTION: Beginning with the January–February 2023 issue, *The Earth Observer* will be published exclusively online.

To receive notification when new issues are published online your email address *must* be registered on our subscription list. Turn to page 43 of this issue to subscribe, so you can stay connected to *The Earth Observer* beginning with **Volume 35**. Discontinuing *The Earth Observer* as a print publication after almost 34 years was a difficult decision to make. However, we believe it is the best choice at this time to position the publication and its staff to thrive in a future where communication is increasingly digital.

The Joint Polar Satellite System–2 (JPSS-2) launched in the early morning hours of November 10, 2022, on an Atlas V *401* rocket from Space Launch Complex 3 (SLC-3E) at Vandenberg Space Force Base (VSFB) in California. This was the final launch for the Atlas V from VSFB.

JPSS-2 (which will become known as NOAA-21 after the successful launch and on orbit checkout) is officially considered the third satellite of five planned for the JPSS series, which is a NASA–NOAA partnership. JPSS-2 will join JPSS-1 (now known as NOAA-20), launched in 2017, as well as the Suomi National Polar-orbiting Partnership (Suomi NPP), launched in 2011. Suomi NPP was created to be the bridge mission between EOS and JPSS. JPSS-3 and JPSS-4 are planned for 2027 and 2032 launches, respectively.

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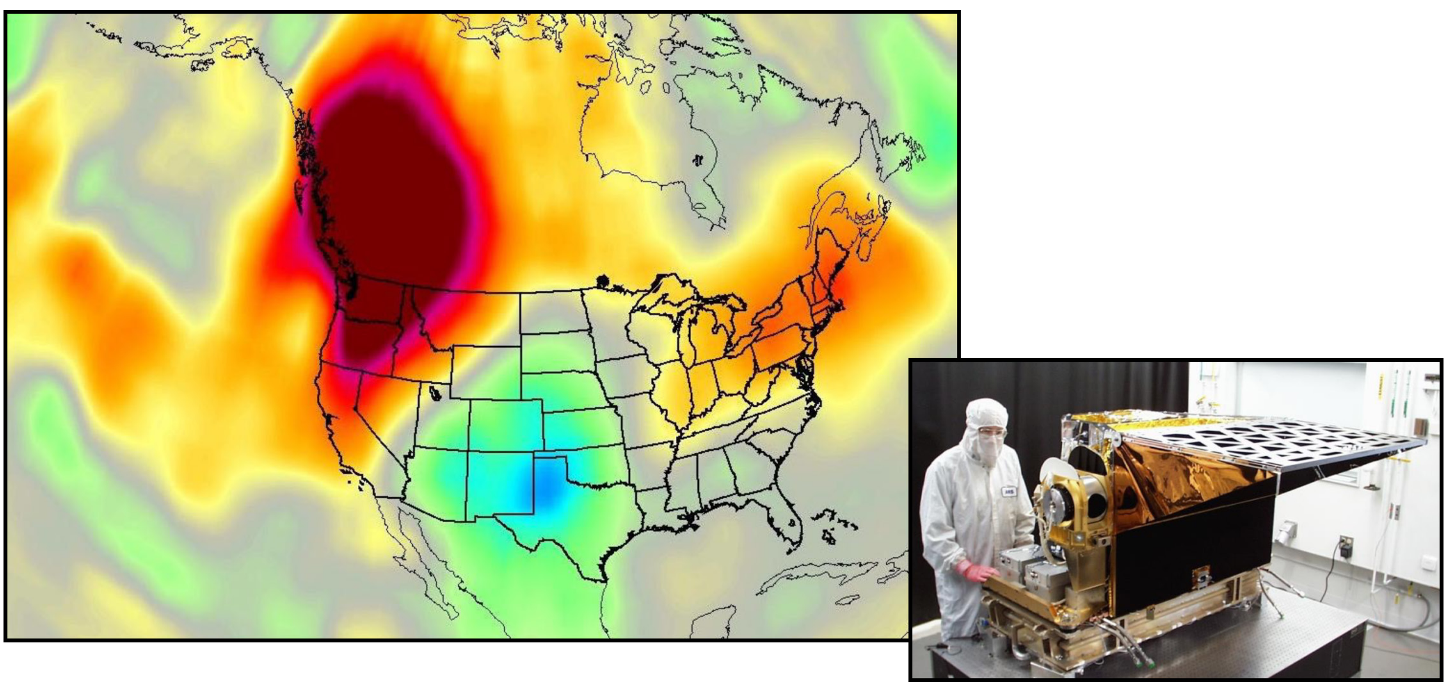

Figure: The Atmospheric Infrared Sounder (AIRS) instrument on the Aqua spacecraft celebrated twenty years of operations recently. The inset photo is referred to as the "AIRS baby picture," which shows the AIRS instrument in the clean room at NASA/Jet Propulsion Laboratory (JPL) circa 2002—prior to being integrated on the Aqua spacecraft. Twenty years later, AIRS remains a vital resource for weather forecasting, and it has also become a resource for understanding the role of climate change in extreme weather events. The image shows data that AIRS obtained during a record-breaking heat wave as it intensified over the Pacific Northwest on June 30, 2021. The daytime surface air temperature anomaly shows up clearly; the dark patch is about 8 °C (15 °F) above average. **Inset photo credit:** JPL; **Image credit:** Charles Thompson/JPL

In This Issue

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

The suite of Earth observing instruments onboard JPSS-2 (very similar to those on Suomi NPP and JPSS-1)[1] are designed to provide full global coverage twice a day. One in orbit, at about 833 km (512 mi) in altitude, JPSS-2 will capture data that has a wide range of uses, including weather forecasting, disaster preparedness, environmental monitoring (e.g., coastal ecosystems, drought conditions, fire, smoke, dust, snow and ice, sea surface temperature, ocean color) and climate data record continuity.

Although the JPSS instruments were not designed as follow-ons to the instruments on the EOS Flagship missions, selected science products from Suomi NPP and NOAA-20 continue many critical EOS data records—for the afternoon overpass, which is similar to Aqua's and Aura's orbital tracks—using, to the extent possible, consistent algorithms as well as radiative transfer models and ancillary data sources. This enables the production of unified multidecadal data records that are key to understanding and quantifying change. The measurements from JPSS-2 (and eventually -3 and -4) will continue to extend these data records well into the next decade.

[1] Suomi NPP, NOAA-20, and JPSS-2 (to be renamed NOAA-21) all include ATMS, CrIS, OMPS, and VIIRS as part of their payload. There is a Clouds and the Earth's Radiant Energy System (CERES) instrument on Suomi NPP and NOAA-20—but not on JPSS-2. (Libera, chosen as Earth Venture Continuity–1, will replace CERES on JPSS-3.) OMPS is composed of limb-viewing and nadir-viewing instruments. Both instruments fly on Suomi NPP and JPSS-2—but only OMPS-Nadir flies on NOAA-20. More details on the JPSS instruments and the payload on each satellite can be found at *nesdis.noaa.gov/current-satellite-missions/currently-flying/joint-polar-satellite-system/jpss-mission-and*.

Next in the VSFB launch queue after JPSS-2 is the Surface Water and Ocean Topography (SWOT) mission. The fully integrated and tested satellite was shipped back from France, where it had been undergoing testing, to VSFB on October 16. Since then, it has been undergoing final preparations for launch, currently scheduled for December 12 from Space Launch Complex 4E via a SpaceX Falcon 9 rocket.

SWOT is a partnership between NASA and the Centre National D'Études Spatiales (CNES) [French Space Agency], with contributions from the Canadian Space Agency (CSA) and United Kingdom Space Agency (UKSA) that will conduct the first-ever global survey of Earth's surface water—lakes, rivers, as well as fine-scale ocean topography. SWOT's instruments (the primary one being the K_a-band Radar Interferometer, or KaRIN) will be able to resolve ocean features like currents and eddies less than 100 km (60 mi) across, lakes and reservoirs larger than 6 hectares (15 acres), and rivers wider than 100 m (330 ft). These resolutions are significantly better than current observations of freshwater bodies.

The SWOT Science Team (ST) includes researchers from around the globe, with expertise in oceanography and hydrology.[2] This multidisciplinary group is tackling pressing issues such as freshwater availability, changing oceans and coasts, and much more. The SWOT ST was renewed in 2020 and was organized into working groups that held regular virtual meetings

[2] To learn more about the SWOT Science Team and the research projects that team members are pursuing, please see *swot.jpl.nasa.gov/science/science-team-projects/?order=created_at+desc&per_page=50&page=0&search=&fs=&fc=229&ft=&dp=&category=229.*

over the past two years. The first in-person meeting of the current ST was held June 27–30, 2022, in Chapel Hill, NC. According to **Lee–Lueng Fu** [JPL—*SWOT Project Scientist*] the meeting went well and, after review and discussion of their progress, the team is ready for the mission's launch. In a recent video, NASA promotes the SWOT launch as the vanguard of a "new era of Earth science," to be followed by the missions of the Earth System Observatory.[3] To learn more about the SWOT mission see *swot.jpl.nasa.gov*.

The lead article in this issue summarizes the AIRS/Sounder ST meeting that took place May 10–12, 2022, at JPL. The meeting dates closely corresponded with the twentieth anniversary of the launch of Aqua on May 4, 2022.[4] Therefore, the meeting was organized to be a celebration of the scientific insights and societal benefits provided by twenty years of observations from the AIRS/AMSU/HSB. Given the milestone anniversary for Aqua and the AIRS suite, the format was somewhat different from the typical AIRS/Sounder ST meeting. While there were still presentations on activities involving weather, climate, atmospheric composition, instrument operations, data processing, and other relevant subjects, presenters were also encouraged to provide a historical perspective of their AIRS experience.

From an overview presentation on twenty years of Aqua observations to specific memories of individual experiences working on developing the AIRS instrument, to detailed accounts of how the data are being used today (e.g., see **Figure** on page 1), the breadth of the presentations at the meeting reflected the length of the AIRS record, the many insights it has provided, and the many people who contributed to its creation and analysis. This work has resulted not only in over 1000 peer-reviewed publications, but also significant economic benefits from improved monitoring and forecasting. Turn to page 4 of this issue to read more about this meeting.

Turning now to current missions, the the July–August 2022 issue of *The Earth Observer* reported on the successful launch and installation of the Earth Surface Mineral Dust Investigation (EMIT) on the International Space Station (ISS)—and showed its first-light image.[5] EMIT has wasted no time validating performance in orbit and producing mineral composition results. See, for example, *climate.nasa.gov/news/3223/nasa-dust-detective-delivers-first-maps-from-space-for-climate-science*.

In addition, in the data collected since July, EMIT's high-fidelity imaging spectrometer has detected over 50 methane *super-emitters* around the world. These are facilities, equipment, and other infrastructure, typically in the fossil-fuel, waste, or agriculture sectors, that emit methane at high rates. To learn more see *climate.nasa.gov/news/3228/methane-super-emitters-mapped-by-nasas-new-earth-space-mission*.

Continuing on ISS, the Stratospheric Aerosol and Gas Experiment III/International Space Station (SAGE III/ISS) mission marked the fifth anniversary of its launch earlier this year. SAGE III/ISS is a climate continuity mission that monitors the vertical distribution of aerosol, ozone, water vapor, and other trace gases in Earth's stratosphere and troposphere. Over more than five years, SAGE III/ISS has collected data during several natural disasters, allowing researchers to study the resulting impact on atmospheric chemistry and energy budget. For example, the historically large injection of smoke into the stratosphere from the Australian bushfires of 2019–2020 significantly perturbed the stratospheric ozone cycle. Researchers found that important chemistry can occur on smoke particle surfaces, which in turn contributes to the loss of ozone—which continues to be a hot topic of research. More recently, SAGE III/ISS observed changes in upper atmosphere chemistry resulting from the spectacular

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List of Undefined Acronyms Used in Editor's Corner and/or Table of Contents

ABoVE	Arctic-Boreal Vulnerability Experiment
AIRS	Atmospheric Infrared Sounder
AMSU	Advanced Microwave Sounding Unit
EOS	Earth Observing System
Fire-IT	Fire Monitoring and Mapping Implementation Team
GOFC	Global Observation of Forest and Land Use Dynamics
GWIS	Global Wildfire Information System
HSB	Humidity Sounder for Brazil
JPL	NASA/Jet Propulsion Laboratory
LANCE	Land, Atmosphere Near-real-time Capability for EOS

[3] To view the video, see *science.nasa.gov/earth-science/earth-information-center*. SWOT is mentioned beginning at *0:18*. More information on the Earth System Observatory can be found at *science.nasa.gov/earth-science/earth-system-observatory*.
[4] The twentieth anniversary of Aqua was the focus of two articles in the May–June 2022 issue of *The Earth Observer* [**Volume 34**, **Issue 3**—*eospso.nasa.gov/sites/default/files/eo_pdfs/May%20Jun%202022%20color%20508.pdf#page=4*]. See "Aqua's 20 Years Honored with Celebration at the Goddard Visitor's Center" on p. 4, followed immediately by "Aqua Turns 20" on pp. 5–12].
[5] See "The Editor's Corner" of the July–August 2022 issue of *The Earth Observer* [**Volume 34**, **Issue 4**, p. 1].

A Celebration of Twenty Years of AIRS History and Observations

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Photo 1. Some of the in-person participants at the 2022 NASA AIRS/Sounder Science Team Meeting and Aqua/AIRS twentieth anniversary celebration. **Photo credit**: Wing Sze Lui/JPL

Introduction

The NASA atmospheric sounding community held a science team meeting (STM) May 10–12, 2022, at NASA/Jet Propulsion Laboratory (JPL) in commemoration of the twentieth anniversary of the launch of Aqua on May 4, 2022—and in celebration of the scientific insights and societal benefits provided by twenty years of observations from the Atmospheric Infrared Sounder (AIRS)/Advanced Microwave Sounding Unit (AMSU)/Humidity Sounder for Brazil (HSB) suite.[1] Given the long and rich record from AIRS/AMSU/HSB—and from the AIRS instrument in particular—this community had much to share in this meeting—and much to celebrate. This hybrid meeting marked the effective end of remote work initiated in March 2020 as the COVID-19 pandemic impacted all our lives. In keeping with the ongoing seriousness of the pandemic, virtual meeting attendance was an option—and about half of the 100 meeting attendees opted to participate remotely. **Photo 1** shows some of the in-person participants.

The summary report that follows begins with information on AIRS/AMSU/HSB to place it in the context of the Aqua mission, continues with some background on the AIRS instrument, and then provides a summary of the meeting. While this is not intended to be a comprehensive report, it does highlight the meeting's major points of emphasis. For more complete coverage of these and other topics discussed, visit the AIRS webpage at *airs.jpl.nasa.gov*. The meeting agenda and many of the presentations are available at *go.nasa.gov/3fwlmFR*.

AIRS/AMSU/HSB in the Broader Context of Aqua

In the early hours of May 4, 2002, NASA's Aqua spacecraft was launched from Vandenberg Air Force Base (now Space Force Base) in California. Its payload included the AIRS/AMSU/HSB suite[2]—the focus of this article—as well as the Advanced Microwave

[1] The AIRS instrument was coboresighted with AMSU and HSB—both state-of-the-art microwave sounders—to create a suite of instruments that could provide vertically-resolved information about the atmosphere, including thermodynamics, water vapor, and clouds, along with surface properties. These water-related observations, along with others from the full complement of Aqua instruments, gave the spacecraft its name.

[2] The design and construction of AIRS was managed by NASA/Jet Propulsion Laboratory (JPL); AMSU was managed by NASA's Goddard Space Flight Center (GSFC); HSB was a contribution from the Brazilian National Institute for Space Research [Instituto Nacional de Pesquisas Espaciais (INPE)].

Scanning Radiometer–EOS (AMSR-E),[3] two copies of the Clouds and Earth's Radiant Energy System (CERES) instrument,[4] and the Moderate Resolution Imaging Spectroradiometer (MODIS).[5]

Claire Parkinson [NASA's Goddard Space Flight Center (GSFC)—*Aqua Project Scientist*] gave a presentation on "Aqua at Twenty" near the beginning of the meeting, which highlighted some of the many accomplishments of the Aqua mission and helped to place AIRS in the larger context of Aqua. She began with a description of the spacecraft and its instruments, and noted some of the key water-related quantities it measures, some involving combining data from more than one Aqua instrument. These include MODIS and AMSR-E ocean surface temperature, MODIS ocean chlorophyll, MODIS Antarctic ice shelf collapse imagery, AMSR-E sea ice, AIRS atmospheric temperature and water vapor, MODIS and AIRS clouds, and AMSR-E rain rates. Parkinson also showed decadal-scale variations in several quantities related to climate change, including CERES reflected shortwave and outgoing longwave radiation (OLR) and top-of-atmosphere net radiative flux, AIRS mid-tropospheric carbon dioxide and methane, AIRS surface warming, and AMSR-E Arctic sea ice extent. **Figure 1** shows a time series of global mean surface temperature from AIRS and other sources. She also showed some air-quality-related quantities, including MODIS dust imagery, AIRS dust and sulfur dioxide (SO_2) from volcanoes, and AIRS carbon monoxide (CO) from fires and human activities. In the field of scientific applications, Parkinson noted the contributions AIRS made to weather forecasting early in the mission—the single greatest improvement in forecast skill from any instrument up to that time —and continuing. She also listed 10 non-NASA federal agencies making use of Aqua data and showed several practical applications of the data, one example being the use of CERES flux products by the energy and agricultural communities. These were just a few examples of the research and applications supported by Aqua data.

Parkinson closed her presentation with a discussion of the drifting Aqua orbit. For its first nearly 20 years, Aqua was maintained in a tightly controlled orbit with mean local equatorial crossing times (MLT) of approximately 1:30 PM and 1:30 AM. However, beginning in January 2022 the orbit was allowed to drift and Aqua is now moving slowly into a later local time. This drift will continue and is expected to reach 3:50 AM/PM MLT in late summer 2026, which is projected to be the time at which the solar array will no longer receive sufficient sunlight to fully power the spacecraft and its still-operating instruments. Parkinson noted the opportunities that this drift offers for future research. She also stated that Aqua has enough fuel remaining for spacecraft lowering maneuvers in 2026, followed by a reentry of the spacecraft into the lower atmosphere within 25 years—meeting the 25-year requirement set by NASA.

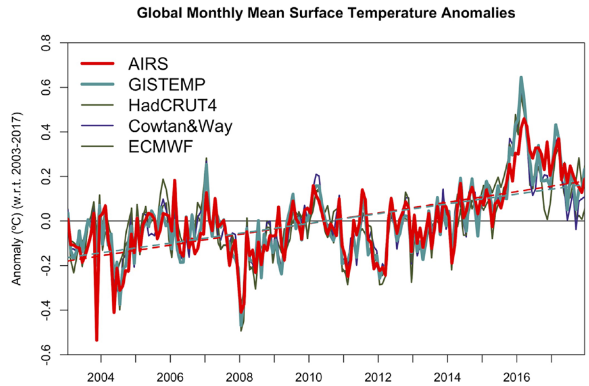

Figure 1. Time series of the global, monthly mean surface temperature anomaly derived from AIRS retrievals [red], the Goddard Institute for Space Studies Surface Temperature Analysis (GISTEMP) *in situ* observations [green], the Hadley Center/Climatic Research Unit (HadCRUT4) *in situ* observations [black], a corrected form of HADCRUT4 (designated Cowtan&Way in the figure, in reference to the HADCRUT4 study authors) [blue], and the European Centre for Medium-range Weather Forecasts (ECMWF) model reanalysis product [gray]. Consistency between AIRS retrievals, *in situ* observations, and the reanalysis products confirm that all datasets are observing realistic warming. **Figure credit:** Joel Susskind/GSFC, and coauthors

This being an AIRS/Sounder STM, the remainder of this summary will focus primarily on AIRS/AMSU/HSB.[6]

Background on the AIRS Instrument

The AIRS instrument was the first hyperspectral infrared (IR) sounder intended for operational use. It included 2378 spectral channels—two orders of magnitude more than the 20 channels on the operational High Resolution Infrared Radiation Sounders (HIRS)

[3] A follow on to AMSR-E, called AMSR2, flies on the Japan Aerospace Exploration Agency's (JAXA) Global Change Observation Mission–Water (GCOM-W), or "Shizuku," satellite. GCOM-W is part of the international Afternoon, or "A-Train," constellation, which until recently also included Aqua, and still includes Aura and several other NASA missions. To learn more, see *atrain.nasa.gov.*

[4] Two CERES instruments also fly on NASA's Terra platform, one on the joint NASA–NOAA Suomi National Polar-orbiting Partnership (NPP) mission, and one on the NOAA-20 mission.

[5] A MODIS instrument also flies on NASA's Terra platform.

[6] To learn more about the Aqua mission's achievements and those of AMSR-E, CERES, and MODIS, see "Aqua Turns 20" in the May–June 2022 issue of *The Earth Observer* [**Volume 34, Issue 3, pp. 5–12**—*go.nasa.gov/3fzWxsF*], as well as the Aqua mission website and individual instrument's websites.

that have provided daily observations of the atmosphere since the mid-1970s.[7]

The high spectral resolution of AIRS gave an added bonus by providing information about atmospheric composition. While AIRS spectral bands were selected to include measurements of the near-global ozone (O_3) contributions, other spectral regions intended for sounding temperature and water vapor have provided useful information about atmospheric composition. Along with the observations of water-related substances and O_3, AIRS has provided information about CO, methane (CH_4), carbon dioxide (CO_2), and other trace gases.

After twenty years in orbit, the AIRS suite continues to operate. While HSB failed in February 2003 and AMSU has lost several channels over two decades of operation, the performance of the AIRS instrument itself has varied little since launch. Sampling at a rate of about 40 spectra per second, AIRS has observed a total of twenty billion spectra, or about 50 trillion individual data points pertaining to Earth. The AIRS radiances provide a richly detailed record of a wide range of weather, climate, and composition processes. These observations are stable enough to discern even small changes in climate. Some noteworthy contributions made by AIRS, which will be discussed more in presentation summaries that follow, are: significant improvements in weather forecast skill immediately after the start of instrument operations; new insights into the behavior of atmospheric hydrological processes from the boundary layer into the upper troposphere; a detailed record of Arctic atmospheric warming and moistening; and monitoring changes in the atmosphere's chemical state. The two decades of AIRS observations also demonstrate significant evidence of human-caused changes to Earth's climate and atmospheric composition.[8]

Meeting Overview

The theme of the May meeting was different from that of earlier Sounder STMs. While presenters were encouraged to focus on the usual topics of weather, climate, atmospheric composition, instrument operations, data processing, and other subjects relevant to atmospheric observation with satellites, they were also encouraged to provide historical perspective of their experiences with AIRS (which from this point on when used alone refers to the AIRS/AMSU/HSB suite)[9]—including the earlier days of development of the three instruments. Gathering at the JPL venue was also a first, as other spring meetings had been held for many years at the nearby campus of the California Institute of Technology. The 2022 meeting included poster sessions—another first for Sounder STMs.

The breadth of the presentations at the meeting reflects the length of the AIRS record, the many insights it has provided, and the many people who contributed to its creation and analysis. This work has resulted not only in over 1000 peer-reviewed publications, but also significant economic benefits from improved monitoring and forecasting. And now, as the end of the Aqua mission draws closer, this is also a time of transition for the AIRS instrument and science community. What follows is a sampling of what was presented at the meeting.

Presentation Summaries

While Claire Parkinson's presentation placed AIRS in the larger picture of Aqua, **João Teixeira** [JPL—*AIRS Science Team Leader*] focused his remarks on the specific achievements of AIRS, as he discussed "Climate of the 21st Century from an IR Perspective: Twenty Years of AIRS." He showed a figure illustrating the impact of AIRS data on weather forecasts—see **Figure 2** on page 7—which was one of the first major achievements of the instrument. Teixeira also presented overviews of some of the scientific contributions that AIRS has made. For example, IR radiances—which are the basic observations made by AIRS—include large gravity wave signals. These have helped make important advances in our understanding of middle-atmospheric dynamics. This important field of research was unforeseen at the time of Aqua's launch. (See the summary of Joan Alexander's presentation, below.) Given the long record, AIRS has also observed several El Niño–Southern Oscillation (ENSO) cycles, with robust temperature and water vapor signals. AIRS samples extreme convective weather events, as measured by the coldest cloud-top temperatures and the data are analyzed for trends, which show that the coldest cloud tops become more frequent at high surface temperatures—suggesting increasing storm severity as the climate warms. At higher latitudes, AIRS has revealed significant changes in Arctic climate. (See the summary of the presentation by Linette Boisvert, below.) Teixeira also showed how AIRS is being used to assess climate model performance, including models in the Sixth Assessment Report (AR6) published by the Intergovernmental Panel on Climate Change (IPCC). He then showed how AIRS observations can be related to human health-related factors, including relative

[7] The first HIRS instrument flew on Nimbus-6, which was launched in 1975. The design was upgraded several times (HIRS/2, /2I, and /3) for flights on the National Oceanic and Atmospheric Administration's Polar Orbiting Environmental Satellites (POES), a.k.a., the NOAA series, between the late 1970s and 2009. Of those, NOAA-15, -18, and -19 are still operational. NOAA also provided HIRS/4 instruments for the European Organisation for the Exploitation of Meteorological Satellites' (EUMETSAT) MetOp-A and MetOp-B missions.

[8] To learn more about what AIRS has accomplished, see "AIRS at 20 Years: A Bounty of Data," *airs.jpl.nasa.gov/news/185/airs-at-20-years-a-bounty-of-data.*

[9] Any references to the "AIRS instrument" alone will be explicitly labeled as such.

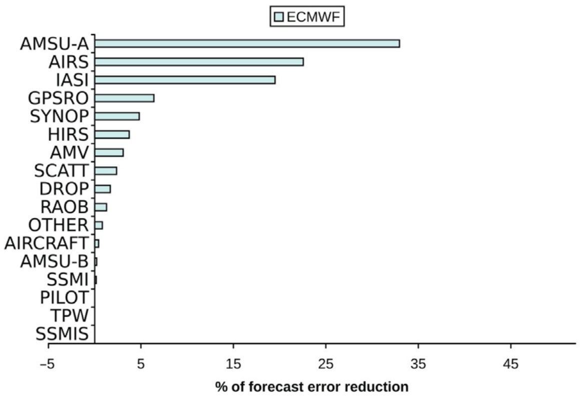

Figure 2. The bar graph above shows the percentage by which the error in the European Centre for Medium-range Weather Forecasts' numerical weather predictions (for 60 °S–90 °S) has been reduced by merging data/observations from the various sources listed on the y-axis [acronyms defined below]. While the greatest overall reduction in error has come from incorporating AMSU-A data, this is the cumulative impact from incorporating data from four different AMSU-A instruments. AIRS provides by far the greatest improvement achieved by a single instrument. IASI is close behind AIRS, but again this represents the gain from incorporating data from three IASI instruments. **Figure credit:** Boullot, et al. (2014), doi: 10.1002/qj.2470

humidity as a predictor of influenza cases and the effect of the COVID-19 pandemic on CO levels over densely populated eastern China. Teixeira finished his survey of science results by showing trends generated from the 20-year AIRS record, including Arctic warming and a clear decrease in atmospheric CO. He closed by reiterating Aqua's currently drifting orbit and noting the significant value of observations from later in the diurnal cycle as a result.

Tom Pagano [JPL—*AIRS Program Manager*] gave a report on "AIRS Project Status and Highlights since Launch." His experience with AIRS began around 2000, when he took on the responsibility of calibrating the newly completed AIRS instrument. In his presentation Pagano provided many details of the activities in the critical two years prior to launch and noted his experience on MODIS calibration prior to joining the AIRS effort. He showed many photographs of coworkers taken as early as the 1990s—which was a trip down "memory lane" for many in the room. Included among them were numereous pictures of **Moustafa "Mous" Chahine**—who led the AIRS team from the early days of development of the AIRS, AMSU, and HSB instruments until his passing in March 2011. Pagano emphasized the critical contributions Chahine made to the development and success of AIRS. A single bullet point in his presentation summarized the many distinguished honors Chahine achieved during his career, which included: Fellowship in the American Physical Society, the American Association for the Advancement of Science, the American Geophysical Union, the American Meteorological Society, and the British Meteorological Society.[10] Chahine was also a friend and mentor to many who were involved with the AIRS project. Pagano showed the excellent performance of AIRS over its 20-year life—a fitting tribute to Chahine and his remarkable life. He also shared a list of societal applications that AIRS data have supported.

Will McCarty [NASA Headquarters—*Aqua Program Scientist*] talked about "AIRS, NWP[11] and Me: Twenty Years of AIRS, with Thoughts on What's Next." Setting the theme for several early-career presenters at the meeting, McCarty described working at a hardware store when AIRS was launched in May 2002. He later became very familiar with the AIRS datasets while working on his PhD in data assimilation at the University of Alabama in Huntsville, completed in 2008. His graduate work led to a position studying data assimilation at the Global Modeling and Assimilation Office (GMAO) at GSFC using a variety of satellite datasets. McCarty described future prospects for

[10] While not listed on the slide, Chahine was also a member of the National Academy of Engineering.
[11] NWP stands for Numerical Weather Prediction.

List of Acronyms Used in Figure 2.

AIRCRAFT	Aircraft
AIRS	Atmospheric Infrared Sounder [Aqua]
AMSU-A	Advanced Microwave Sounding Unit–A [Aqua and NOAA-15–18]
AMSU-B	Advanced Microwave Unit–B [NOAA-15–17]
AMV	Atmospheric Motion Vector
DROP	Dropsonde
GPSRO	Global Positioning System/Radio Occultation
HIRS	High-resolution Infrared Radiation Sounder [MetOp]
IASI	Infrared Atmospheric Sounding Interferometer [MetOp]
OTHER	Other Sources (e.g., ship and surface measurements)
PILOT	Balloons (tracked from the ground)
RAOB	Radiosonde observations
SCATT	Scatterometer
SSMI	Special Sensor Microwave/Imager [Defense Meteorological Satellite Program (DMSP)]
SSMIS	Special Sensor Microwave Imager/Sounder [DMSP]
SYNOP	Synoptic
TPW	Total Precipitable Water

satellite remote sensing—including the value of data from a wide assortment of sensors in a variety of orbits. Following up on Claire Parkinson's earlier remarks, McCarty noted the value of collecting AIRS data as Aqua's orbit drifts. He said that observations from local times other than 1:30 AM/PM MLT will provide insights into processes not commonly observed and can serve as a pathfinder for the design of planned hyperspectral IR instruments to be inserted into geosynchronous orbit.

Fred O'Callaghan [JPL, *retired—Former AIRS Project Manager*] appropriately titled his presentation: "AIRS 20th Anniversary Celebration." He was project manager for AIRS during instrument development and the first several years of operations. Following up on Tom Pagano's remarks, O'Callaghan acknowledged Mous Chahine's vision and drive. He noted that the first planning meetings for AIRS began in 1986, formal instrument development began in 1987, and hardware development began in 1991.[12] The instrument was delivered for integration and testing in 1999. He also reported that over 500 people worked on the development of the AIRS instrument during peak activity. This was a time of significant shifts in the aerospace industry, and the companies building hardware underwent several name changes, so the number of companies contributing to AIRS success was also noteworthy. O'Callaghan listed numerous technology developments required for the success of the AIRS instrument, including long-life coolers, scanning mechanisms, detector arrays, spectrometer gratings, IR filters, and readout electronics. The remarkable scientific achievements using AIRS data clearly rest upon equally remarkable engineering achievements. **Photo 2** shows part of the AIRS development team around the time of Aqua's launch in 2002.

Hank Revercomb [University of Wisconsin–Madison (UWM)] gave a presentation titled "Happy Anniversary for Atmospheric Infrared Sounding: A Historical Perspective and Big-Picture Vision of the Next Steps." He pointed out that the theoretical justification for IR sounding was presented in a paper by Louis Kaplan published in 1959. Collaboration with Kaplan was a reason for Mous Chahine's advocacy of IR sounding in the 1960s, as noted earlier, and Kaplan was an early member of the AIRS science team.

Revercomb noted that his own involvement with remote sounding began in 1974, when he started working with Verner Suomi at the Space Science and Engineering Center (SSEC) at the University of Wisconsin–Madison. Suomi was an early faculty member in the department of Meteorology at the UWM, founder of the SSEC, a key figure in the development of meteorological satellites by the U.S. and other governments, and the namesake of the Suomi National Polar-orbiting Partnership, or Suomi NPP satellite.

Revercomb also described the development of aircraft-borne IR spectrometers at the University of Wisconsin. That work involves technology advancements alongside science analyses, including validating satellite instruments. Developing this hardware ultimately led to the Cross-track Infrared Sounder (CrIS) carried on Suomi NPP and on two Joint Polar Satellite System (JPSS) satellites, one of which is in orbit (now renamed NOAA-20), the other planned for a November

[12] The late Crofton "Barney" Farmer had been Chahine's group supervisor and recalled him advocating for a hyperspectral atmospheric sounding instrument in orbit as early as 1968. Chahine later spent a sabbatical year in the 1970s with Jule Charney at the Massachusetts Institute of Technology working on the concept.

Photo 2. Some of the JPL contributors to the AIRS science and instrument activities in 2002. The location is the same as Photo 1. **Fred O'Callaghan** is directly behind the AIRS sign [center]. **Mous Chahine** stands immediately to the left of Fred in the front row. **Photo credit:** JPL

2022 launch. Three Infrared Atmospheric Sounding Interferometer (IASI) instruments, flown and operated by EUMETSAT, follow a similar design. Revercomb noted that all data from operating AIRS, CrIS, and IASI hyperspectral IR sounders agree to within a fraction of a Kelvin (K) in brightness temperature when they view identical scenes. This remarkable achievement was made possible through the work of hundreds of people around the world, and is the foundation of the weather, climate, and composition advancements made by AIRS and other sounders. He also noted some of the steps needed for further advancements in IR remote sensing, which include: better time coverage through SmallSats in a mix of local times,[13] a ring of hyperspectral sounders in geosynchronous orbit, and a set of dedicated reference sensors with demonstrable in-orbit calibration stability. Those reference sensors would then be used as a baseline to establish the stability of other satellite sensors.

Vivienne Payne [JPL] gave a presentation titled "Atmospheric Composition in the Past, Present, and Future: A View from Hyperspectral IR Sounders." She began the presentation by describing the Interferometric Monitor for Greenhouse Gases (IMG) launched on the Japanese Advanced Earth Observing Satellite (ADEOS) in 1996. Though ADEOS operated for less than a year, IMG included IR spectral coverage and resolution roughly comparable to AIRS, CrIS, and IASI, and to the Tropospheric Emission Spectrometer (TES) carried on the Aura spacecraft.[14] The IMG data helped set the stage for composition studies with those instruments.

Payne also showed the value of combining hyperspectral IR observations (i.e., from AIRS, CrIS, and TES) with observations from other instruments, including MOPITT, OMI, and TROPOMI.[15] She described the synergistic use of collocated and near-simultaneous data from multiple instruments, made possible by their placement in the NASA A-Train constellation. The resulting retrievals have better performance than those of either contributing instrument. She also shared results on a remarkable number of trace gases, including: CO (from AIRS, MOPITT, CrIS and TROPOMI); O_3 (from AIRS, TES, OMI, and TROPOMI); ammonia (NH_3) (from AIRS, TES, and CrIS); peroxyacetyl nitrate (from TES and CrIS); ethylene and isoprene (from CrIS and TES); and methanol (from TES). The processes observed include stratospheric intrusions (for O_3), fire plumes (for several gases), and anthropogenic and natural trends (for NH_3, O_3, and CO). Payne noted that the spectral signals of some of those gases are of the order 0.05 K, and their detection is only made possible by high spectral stability and careful averaging. She described a system to assimilate all these constituents into a chemical transport model.

Payne also showed a list of the 11 hyperspectral instruments that have been placed in low Earth orbit since 2002, plus 5 more that are planned for such insertion between now and the late 2020s. This order-of-magnitude increase in the number of hyperspectral sounders since the launch of AIRS in 2002 is testimony to their value to the international community of data users. She also described several advantages to these datasets, including simultaneous measurements from the Afternoon Constellation, or "A-Train", a variety of retrieval approaches to extract as much information as possible, long-term instrument stability, and low instrument noise. Earlier, Hank Revercomb had similarly noted the last two advantages Payne mentioned as important aspects of the radiance record.

Bjorn Lambrigtsen [JPL] presented "The Aqua Microwave Sounders: Why, What, How." He stated that the basic rationale for the microwave instruments was to provide a first guess for the cloud-clearing methodology developed by Mous Chahine and Bill Smith. A former student of Verner Suomi, Smith became a professor at the UWM and a long-time member of the AIRS science team—and is still active in the atmospheric sounding community. Lambrigtsen showed that AMSU and HSB combined were nearly as massive as the AIRS instrument, drew half the power that AIRS required, and had a total of 19 channels (compared to 2378 on the AIRS instrument alone). AMSU was intended primarily for temperature sounding, while HSB provided water vapor information. Both were carefully coaligned and synchronized with AIRS. Lambrigtsen went on to explain that—in contrast—CrIS and IASI do not use this approach with their companion microwave instruments. He showed some first-light images from the Aqua microwave instruments (from 2002) and gave a timeline for developing microwave hardware and retrieval technologies, starting in the 1980s and continuing with instruments that are follow-ons to those on Aqua. Lambrigtsen closed by noting the value of microwave observations, in that they have much smaller sensitivity than the IR to clouds and precipitation. This advantage has not been fully exploited in the record from all modern satellite systems.

Andy Dessler [Texas A&M University, College Station] started his presentation titled "The Water Vapor Feedback: A Historical Perspective" by noting

[13] SmallSats are satellites with total mass less than about 180 kg (~400 lbs).

[14] While no longer operational, TES was used for atmospheric composition studies and had wider spectral coverage and higher spectral resolution than AIRS, CrIS, or IASI.

[15] MOPITT stands for Measurements of Pollution in the Troposphere; it flies on NASA's Terra platform. OMI stands for Ozone Monitoring Instrument; it flies on NASA's Aura platform. The TROPOspheric Monitoring Instrument, TROPOMI, is a European Space Agency instrument, flying on the European Copernicus Sentinel-5P mission.

that water vapor feedbacks amplify the warming effects of other greenhouse gases—i.e., increased CO_2 and CH_4 cause about 1 K warming—while water vapor feedbacks increase the warming to about 3 K. This mechanism was first presented theoretically in the late 1960s by Syukuro Manabe, a 2021 Nobel Prize winner in physics. Dessler noted that water vapor feedback warming strength had been a subject debated for the ensuing 40 years—largely due to limited observations of upper tropospheric water vapor needed to test its validity. He described his own work, using AIRS water vapor and temperature data and supporting the additional 2 K of feedback-induced warming. This study largely ended the debate about water-vapor feedback strength, and confirmed that model projections of future warming are realistic.

Brian Soden [University of Miami] gave a presentation titled "Monitoring Radiative Forcing and Radiative Feedbacks Using AIRS," which built upon Andy Dessler's presentation. Soden described work to relate processes controlling feedbacks to the resulting changes in OLR. He began by showing a plot of increases in OLR observed by CERES/Aqua, and described the contribution to calculated OLR by individual quantities (e.g., temperature, water vapor, and clouds) retrieved with AIRS data. While an individual quantity's contributions to OLR appear noisy relative to CERES' total OLR, their sum agrees remarkably well with the CERES values. This greatly increases the confidence in OLR measurements from both AIRS and CERES and in the AIRS observations used to calculate OLR; it also confirms that individual AIRS quantities (e.g., temperature, water vapor, and clouds) realistically embody climate processes.

Soden also showed where the large changes in OLR are occurring and added that these regions are similar to those seen in climate model outputs. This increases confidence in the model physics and helps constrain model projections. Returning to the CERES comparisons with AIRS, he showed a slight time trend of 0.5 W/m^2 in their difference over two decades. Because the AIRS OLR calculation did not account for changes in greenhouse gas forcing, he attributed the trend to increasing greenhouse gases. Soden cited this as further evidence for the value of stable AIRS radiances.

Joan Alexander [Northwest Research Associates, Boulder, CO] provided "Global Perspectives on Small-scale Atmospheric Gravity Waves from AIRS." Alexander has been an international leader in studying gravity waves using AIRS observations. She noted the importance of gravity waves in atmospheric general circulation—as they carry momentum—and that gravity-wave momentum flux is a dominant factor in the behavior of the mesosphere. She also presented a more general overview of gravity wave observations. Alexander showed examples of very strong stratospheric gravity waves observed by AIRS over the southern Andes Mountains and gave estimates of the momentum flux carried by these waves. She also showed gravity waves over vigorous convection and presented a global climatology of very strong waves observed by AIRS. Alexander compared AIRS waves with those in high-resolution models and thereby demonstrated the value of those observations in constraining the model physics. She showed examples that indicate that gravity waves are important in phenomena as diverse as polar stratospheric clouds, the equatorial Madden–Julian Oscillation, and global ENSO events. Alexander described an online data archive of global gravity wave properties from AIRS and showed how the Hunga Tonga–Hunga Ha'apai (HT-HH) volcanic eruption in January 2022 in the South Pacific generated anomalously large gravity waves that were observed around the globe by AIRS, CrIS, and IASI. The results received widespread media attention and are the cornerstone of a recent paper in the journal *Nature*.

Greg Elsaesser [Goddard Institute for Space Studies (GISS)] discussed "Top-Down and Bottom-Up Uses of AIRS Temperature (T) and Water Vapor (Q_V) Data in Climate Model Development." He began by giving participants a sense of the complexity of climate models—noting that the GISS computer model includes over 350 subroutines. He described a "top-down" approach of testing large-scale, long-term characteristics of the model simulations against similar quantities, including T and Q_V from AIRS, and other data sources. Elsaesser then showed that the skill of producing the current climate roughly correlates with effective climate sensitivity,[16] although the spread in model-specific climate sensitivity has increased as model complexity has increased over time. One way to reduce this model spread is to use machine-learning techniques to constrain the dozens of numerical parameters within models to realistic combinations. Another approach to reducing model sensitivity spread is to use observations to test basic processes in addition to bulk properties. Elsaesser suggested convective areal coverage as a quantity to test, since areal coverage is a simple metric for very complex cloud systems.

Linette Boisvert [GSFC] discussed "What We've Learned from 20 Years of AIRS Data in the Polar Regions." She began by showing the state of Arctic sea ice in May 2002. (At that time Boisvert was a high school student with an interest in soccer, working her first job in a pizza parlor.) She noted that the early 2000s was a time of transition to the "New Arctic" as sea ice there began to thin dramatically. Much of the remainder of her presentation detailed how AIRS has revealed a changing Arctic. She shared some of her published results of AIRS observations, showing that

[16] Climate sensitivity is the warming induced by increasing greenhouse gases, often specifically calculated as the warming induced by a doubling of atmospheric carbon dioxide.

the Arctic atmosphere became increasingly warm and moist between 2003 and 2015. To better quantify the effects of ice loss, in another study Boisvert and her colleagues used AIRS data to estimate evaporation from a *polynya*—an ice-free area within an ice-covered region—in the Arctic Ocean. They then looked at evaporation over the entire Arctic Ocean. Evaporation changed significantly over the AIRS period, with the largest increases associated with regions of greatest ice loss and ocean surface warming. Another study showed that heat fluxes (where some heat is carried by evaporating water and some by direct transfer between ocean and atmosphere) have been growing in increasingly warmer, ice-free regions of the Arctic. Applying these techniques to the Antarctic, they found broadly similar results as in the Arctic: fluxes are modulated by the presence of sea ice. In a series of studies they examined the effects of Arctic storm systems and found that storms act as a significant heating mechanism by bringing warmer, more moist air from lower latitudes, with storm winds also increasing surface fluxes of heat and moisture. Warmer storms also bring rain, which can melt surface snow and ice. Overall, this work shows that large Arctic changes are partly due to local warming and moistening as heat flows from an ice-free ocean, and partly due to warm, moist air brought from lower latitudes by storms.

Conclusion

Twenty years of exciting advancements in hyperspectral IR remote sensing research and applications have followed the launch of Aqua in 2002. AIRS is just one of several operational IR instruments whose records extend over a decade or more the first IASI instrument was launched in 2006 and the first CrIS in 2011. As shown in many of the presentations at the meeting summarized here, the observational record from sounders contains a wealth of information about weather, climate, and atmospheric composition. Many presenters at the meeting expressed the view that opportunities offered by this record have not been fully leveraged. Only a small part of information in the 20 billion spectra observed by AIRS has been extracted, and the other hyperspectral sounders provide an equally detailed record of even greater size. Converting those details from data to information to knowledge will require careful thinking and persistent effort.

The sounder community is in the fortunate position of having instruments planned to replace those in operation and can look forward to having hyperspectral sounders in geosynchronous orbit within a few years. Their combination of diurnal coverage and information content will provide new insights, and the challenges and opportunities for the sounder community will continue. The resultant explosion of data has generated a grand challenge in remote sounding: creating a reconciled record of retrieved quantities from multiple instruments. This will complement the remarkably consistent radiance records from sounders. These retrieved quantities (e.g., temperature, trace gases) from remote sensing sources (e.g., multiple satellites) become test cases for numerical models so they more correctly represent physical reality. Another grand challenge is model assimilation of cloud-affected radiances. So, while understanding of sounder data has increased dramatically over time, there is still a long way to go to gain an even more complete understanding based on those (and new) data, and much of that journey will require innovative data analysis techniques.

After twenty years of interesting and important contributions, the Aqua spacecraft has begun its final years of operations. The drift into later local times presents yet another—and serendipitous—opportunity for the AIRS instrument. No hyperspectral sounder has taken observations during those critical afternoon hours after 1:30 PM MLT, when weak convection often transitions into severe weather. AIRS in a drifting orbit will observe that convective transition, and a host of other phenomena undergoing changes during the warmest hours of the day. These observations can be compared against the existing 20-year record, and against baseline measurements by CrIS instruments still operating in the 1:30 AM/PM MLT orbit. The last few years of AIRS operations promise to be at least as exciting as the first twenty. ■

The Editor's Corner *continued from page 3*

eruption of Hunga Tonga–Hunga Ha'apai (HT-HH) in January 2022, whose atmospheric impacts are still unfolding.

During the first summer of the pandemic, SAGE III/ISS successfully completed its baseline mission (2017–2020) and was granted extended operations via the Earth Science Division's 2020 Senior Review. With the SAGE III/ISS payload continuing to operate nominally, and the ISS operations agreement newly renewed to 2030, the SAGE III mission has the potential to extend observations through this decade. The latest ST meeting took place October 13–14, 2022, at NASA's Langley Research Center. Approximately 60 scientists and engineers participated in the meeting and discussed the status of the mission, instrument operations, data processing, and results from studies of the various SAGE III science data products (ozone, aerosol, water vapor, nitrogen dioxide, and nitrogen trioxide). The face-to-face option for this hybrid meeting was a welcome contrast to two years of completely virtual science team meetings. For more information on SAGE III/ISS see *sage.nasa.gov/missions/about-sage-iii-on-iss/*. ■

Summary of the Fifth Joint GWIS/GOFC–GOLD Fire-IT Meeting

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Introduction

The Fifth Joint Global Wildfire Information System (GWIS)/Global Observation of Forest and Land Use Dynamics (GOFC–GOLD) Fire Mapping and Monitoring Implementation Team (Fire-IT) meeting was held June 21–23, 2022, in Stresa, Italy. Thirty researchers from academia, government, and nongovernment organizations participated in the meeting, the majority in person (see **Photo**), and several online. The meeting's goals were to review recent progress made by the GWIS and the GOFC–GOLD Fire-IT, to discuss recent developments in fire science and technology, and to determine the prospects for satellite-based fire monitoring and science in the context of forest and natural resource management and other applications. The joint meeting was organized to build collaboration and cooperation across the international fire remote-sensing community. After a brief background on GWIS/GOFC–GOLD Fire-IT, this article summarizes the latest updates on the various fire-related thematic areas presented by the attendees. The full presentations are available at *go.nasa.gov/3LR0xkp*.

Photo. GWIS/GOFC–GOLD Fire-IT in-person meeting participants. **Photo credit:** GWIS staff

Background on GWIS, GOFC–GOLD, and the Fire–IT

The European Commission's Joint Research Center (JRC) in Ispra, Italy, is the host of the GWIS initiative of the Group on Earth Observations (GEO) and the European Union's (EU) Earth-Observation Copernicus programme. The current GEO GWIS work program for 2020–2022 aims to bring together existing information sources at regional and national levels to provide a comprehensive view and evaluation of fire regimes and fire effects at the global level, and to provide tools to support operational wildfire management at national to global scales. Several GEO partner organizations support the GWIS. For example, the Applied Sciences Program of NASA's Earth Science Division funded three U.S. researchers for projects to contribute to GWIS as part of the GEO's work plan (*appliedsciences.nasa.gov/taxonomy/term/132*).

GOFC–GOLD focuses on international coordination of enhanced Earth observations (EO) to improve the quality and availability of space-based and *in situ* observations at regional and global scales. It also seeks to encourage generating and distributing appropriate, timely, and validated products to support sustainable management of terrestrial resources (*gofcgold.org*).

The Fire-IT is one of two GOFC–GOLD implementation teams; the other focuses on Land Cover and Land Use Change. The Fire-IT activities refine and articulate international observation requirements and make the best possible use of fire products from existing and future satellite observing systems for fire management, policy decision making, and global-change research. The Fire-IT comprises experts from national and international space agencies, governmental and nongovernmental environmental organizations, and universities. **David Roy** [Michigan State University, U.S.], **Martin Wooster** [King's College London, U.K.], and **Jesus San-Miguel-Ayanz** [European Commission, JRC] are the current cochairs of the Fire-IT; NASA provides support for the U.S. cochairs of GOFC–GOLD.

MEETING HIGHLIGHTS

GWIS Updates

GWIS provides harmonized, global-scale wildfire information, including the current wildfire danger forecast database. The data are available through Web Map Services (WMS) at the GWIS platform accessible at *gwis.jrc.ec.europa.eu*.

Further, a historical fire danger reanalysis database has been generated in collaboration with the European Centre for Medium-Range Weather Forecasts (ECMWF). GWIS holds the active fire (AF) data derived from the Moderate Resolution Imaging Spectroradiometer (MODIS),[1] which are retrieved from the NASA Land, Atmosphere Near real-time Capability for the Earth Observing System (EOS) [LANCE] system for the period 2000–2017.

The GWIS also has new tools to generate national and subnational burned area (BA) assessment information. The tools provide fire reporting and assessment support, with a country-by-country dashboard to provide easy access to allow evaluating fire information. The possible outputs include monthly and annual total area burnt and the number of AF detections; temporal ranking of fire counts based on the number of months or years of the occurrence; yearly fire seasonality metrics such as the start and end of the fire season; the peak month of burning; annual fire-size metric (e.g., mean, median, and maximum fire-size number); and the minimum size of the fires responsible for 25%, 50%, and 75% of the total annual BA. These tools have been online since February 2021. In addition, new tools to assess *fire danger*[2] are available in GWIS.

Work is in progress to incorporate GWIS-derived emissions into the Emissions Database for Global Atmospheric Research (EDGAR). EDGAR provides a global, independent summary of GHG emission estimates compared to those reported by Member States or Parties under the United Nations Framework Convention on Climate Change (UNFCCC).

GWIS has a budget for 2022–2027 through the EU's Copernicus program;[3] thus, more refinements in the GWIS system are expected. In addition, GWIS is involved with the EU Green Deal Program, which focuses on detecting and controlling deforestation fires, administering environmental governance, monitoring lands of indigenous people, and providing sustainable forest goods and services in Latin American countries.[4]

NASA and NOAA Fire Products

There was a discussion about the most recent NASA MODIS AF and BA products for a variety of NASA and international satellite instruments.

The most recent MODIS AF and BA products were created for Collection 6 (C6). The AF products commenced production in 2015 and the BA products in 2016. All will end processing under C6 in December 2022. All MODIS C6 AF and BA products were transitioned to C6.1 in 2019—including polarization correction and some minor calibration updates—with no change in the AF product, and only small differences in the BA product. The MODIS fire product record (including AF and BA products) will be reprocessed for Collection 7 (planned for late 2023) to ensure a consistent systematically generated global fire record from 2000 to present.

The NASA Visible Infrared Imaging Radiometer Suite (VIIRS) Collection 1 provides two AF products. The 750-m product will be phased out after the transition of downstream applications (e.g., smoke modeling) to the 375-m product—a widely used significant improvement over the MODIS product. Both products provide global, near-real-time (NRT) data through direct broadcast (DB), utilizing the Community Satellite Processing Package (CSPP) software. Planned improvements to the 375-m fire product algorithm include reducing false alarms found over reflective sources (e.g., solar farms); reducing omission errors found over snow-covered areas and under translucent clouds; minimizing the impact of hot plume detections over large wildfires, and implementing atmospheric correction of Fire Radiative Power (FRP) retrievals.

There have been significant improvements to several Collection 2 BA products, including the transition of NOAA-like Sensor Data Records (SDRs) that are time-tagged, geolocated, and calibrated, to a format similar to NASA's L1B data products. The Collection 2 land reprocessed products will be released by early 2023. For Collection 3, the plan is to better capture small burns and cropland BA mapping, including improving the product fidelity by combining Suomi National Polar-orbiting Partnership (NPP) and NOAA-20 VIIRS observations, analogous to combining MODIS Terra and Aqua observations.

[1] A MODIS instrument flies on NASA's Terra and Aqua platforms.

[2] According to the National Park Service, fire danger is defined as an assessment of the combination of both constant and variable factors that affect the initiation, spread, and ease of controlling a wildfire on an area. Learn more at *go.nasa.gov/3dWfNQk*.

[3] The Copernicus Programme is the European Union's (EU) Earth observation program, coordinated and managed for the European Commission by the EU Agency for the Space Programme in partnership with the European Space Agency and the EU Member States.

[4] Learn more about the EU's Green Deal at *go.nasa.gov/3dWWeri*.

The NOAA Geostationary Operational Environmental Satellite–Series R (GOES-R)[5] Advanced Baseline Imager (ABI) AF product is operational for GOES-East and -West[6] in all scanning modes and available via Amazon Web Services (AWS) and from NOAA's Comprehensive Large Array-data Stewardship System (CLASS). Further development efforts are underway towards improved algorithm sensitivity for nighttime fires, reduction of false alarms, terrain correction, improved atmospheric correction, and cloud masking.

The possibility of using data from the METimage sensor on the European Organisation for the Exploitation of Meteorological Satellites' (EUMETSAT) Second Generation Operational Meteorological (MetOp-SG) satellites for AF detection and FRP retrievals is under evaluation.[7] The first MetOp-SG launch is planned for 2024, with launches projected to continue until 2039.

[5] The GOES-R series includes GOES-R, GOES-S, GOES-T, and GOES-U. The first three of these are now known as GOES-16, -17, and -18, respectively. GOES-U is scheduled to launch in 2024 and will become GOES-19 after launch.

[6] GOES satellites operate from two primary locations: GOES-East at 75.2 °W and GOES-West at 137.2 °W. GOES-16 currently occupies the GOES-East position; GOES-18 occupies the GOES-West position; and GOES-17 is the operational spare.

[7] METimage is a visible and infrared radiometer planned for MetOp-SG that is intended to provide continuity to VIIRS and NOAA's Advanced Very High Resolution Radiometer (AVHRR).

Also, NOAA is processing data from the NASA–U.S. Geological Survey's Landsat-8 and -9 missions and the Sentinel-2A and -2B AF product over the U.S., based on reflective-wavelength algorithms. NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) is planning to develop a dedicated NESDIS Fire Information System and web-based user interface, with single or multisource geostationary or low-Earth-orbit (LEO) satellite data integration. The system will include a variety of algorithms specially designed to support legacy needs and to address data gaps, and fire alerts, and enabling the blending of multiple sensors and information sources, including fire incident databases and a cloud-based system with Open Geospatial Consortium (OGC)-compliant product files.

For BA mapping, medium-resolution Sentinel-2 and Landsat-8 and -9 data are valuable assets because they enable mapping of small [10–30 m (33–98 ft)] and spatially fragmented burns. The planned NASA–USGS Landsat Next and next-generation ESA Sentinel-2 missions will continue the global medium-resolution land-cover record—and will be highly useful for BA mapping. In parallel, commercial, high-spatial and high-temporal-resolution data have the potential to

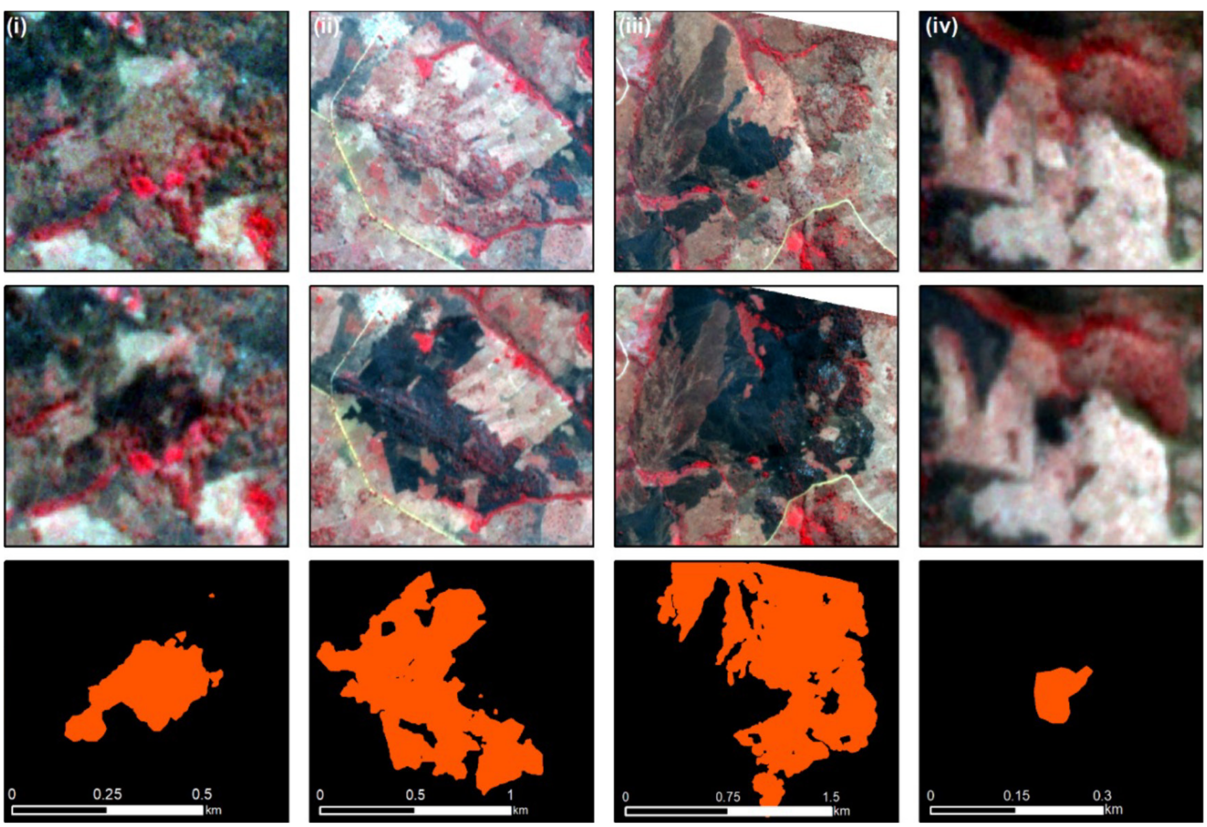


Figure 1. Analysis of different sizes of burned areas (black patches) over Cuanza Sul, Angola, from Planetscope data. The top row shows Planetscope 3-m false color (near infrared/red/green) images on July 24, 2019; the middle row shows relative increase in burn areas by the next day (July 25, 2019); and the bottom row shows classification of burnt areas for July 25, 2019, using the Deep Learning algorithm. **Image credit**: David Roy/Michigan State University

achieve even higher spatial resolution—down to 5 m (~16 ft) or less—e.g., see the high-resolution data from PlanetScope in **Figure 1** on page 14.[8] However, achieving this level of spatial resolution will require overcoming issues related to multisensor calibration, band pass differences, and geolocation issues. Over the past three years there has been growth in artificial intelligence (AI) methods for BA mapping, in contrast to physics-based approaches. Irrespective of the methods used, there is demand for robustly validated and quality-assessed BA products.

European Copernicus Program Fire Products

The Sea and Land Surface Temperature Radiometer (SLSTR) on Copernicus Sentinel -3A and -3B can provide global data for morning hours—similar to the overpass time for MODIS on Terra. Global, daily AF counts and FRP retrievals from Sentinel-3A and -3B from January 2019 are available from the Copernicus Open Data Hub (*scihub.copernicus.eu/dhus/#/home*). The SLSTR thermal infrared channels (denoted as S7–S9, F1, and F2) have a resolution of 1 km at nadir, and the visible–shortwave infrared (VIS-SWIR) channels (denoted S1–S6) have a resolution of 0.5 km at nadir. While the SLSTR S7 channel is most ideal for fire observations, it often saturates. By contrast, the F1 channel tends to be more noisy than S7, but is less susceptible to saturation and thus is more useful than S7 for fire observations.

Preliminary assessments suggest that nighttime observations from SLSTR can be used to detect more AF pixels than similar observations from MODIS—but fewer than observations from VIIRS. Meanwhile, FRP values derived from SLSTR observations are more similar to those derived from MODIS and VIIRS observations. Integration of SLSTR AF data into the NASA Fire Information for Resource Management System (FIRMS) is being considered, as its morning overpass—see **Figure 2** below—can supplement the planned end of life for MODIS Terra observations. (For more information on FIRMS, see "NASA FIRMS Update" on page 16.)

The Fire Climate Change Initiative (CCI) project funded by Copernicus provides multiple global BA products, including intercomparison of BA algorithms. The project will improve consistency for both preprocessing and BA detection and will incorporate error characterization (*climate.esa.int/en/projects/fire*). The project is generating the global pixel-level BA products at a monthly scale with a resolution of 250–300 m. These data include date of detection, confidence level, and land cover classification corresponding to the burned pixel. Each dataset contains one month's worth of information. There was further discussion on the availability of specific data products from several Earth-observing satellites, including examples from several continents.

The Copernicus Atmospheric Monitoring System uses Aerosol Opticel Depth (AOD) measurements from the Global Fire Assimilation System (GFAS) to estimate surface-level concentrations of particulate matter with diameters 2.5 µm or smaller ($PM_{2.5}$) at a global scale. The products are being validated in multiple regions using ground-based $PM_{2.5}$ sensors. One of the presentations in this section highlighted the value of using geostationary satellites to estimate emissions. The study used FRP derived from European Meteosat data and directly linked it to Total Column Carbon Monoxide (TCCO). This work significantly extends the previous Fire Radiative Energy Emissions (FREM) approach that derived Total Particulate Matter (TPM) emission coefficients from FRP measurements and AOD observations. The use of satellite-based carbon monoxide (CO) observations to derive CO emission coefficients addresses key

[8] The PlanetScope satellite constellation (created by Planet Labs) consists of multiple launches of groups of individual CubeSats called Doves that are then delivered into orbit as secondary payloads on other rocket launch missions. Each Dove is equipped with a high-powered telescope and camera programmed to capture different swaths of Earth. To learn more about PlanetScope, see *earth.esa.int/eogateway/missions/planetscope*.

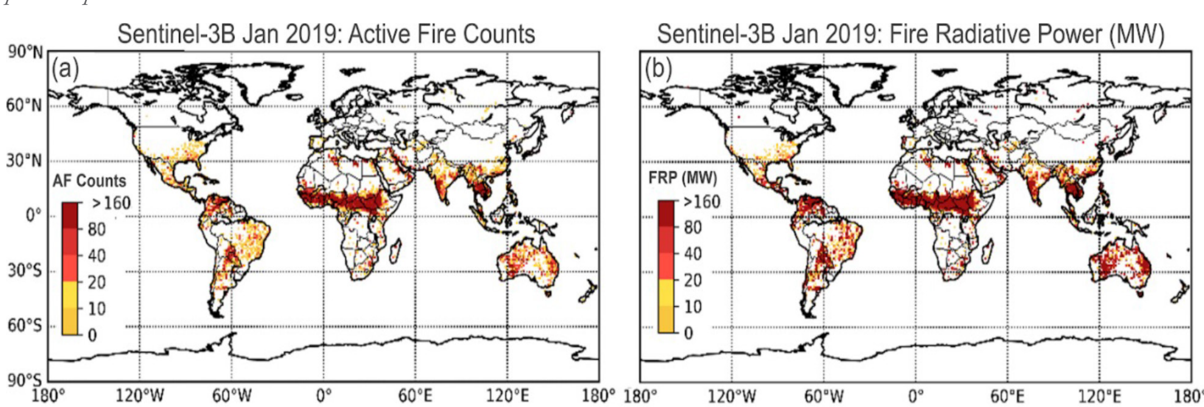


Figure 2. AF [left] and FRP [right] retrievals using data from the Sea and Land Surface Temperature Radiometer (SLSTR) on Sentinel-3B. SLSTR is being proposed as a possible source of continuity for MODIS Fire (and other) Products once the Terra mission ends. **Image credit:** Martin Wooster/King's College London

uncertainties in the use of AOD measures to estimate fire-generated CO emissions, including the requirement for a smoke-mass extinction coefficient in the AOD to TPM conversion; and the large variation in TPM emission factors—which are used to convert TPM emissions to CO emissions from the African continent. This methodology can be extended to the other regions of the world to estimate biomass burning emissions using data from geostationary satellites.

The NASA Wildland FireSense Program

NASA recently initiated a new five-year effort, called NASA Wildland FireSense (hereinafter FireSense), to build partnerships with the wildfire community. In an effort to create the next generation of tools and science-informed capabilities for wildfire-adapted communities and to better enable society to live sustainably with wildland fires, NASA will provide support for wildland fire management, bring together data from different sources, develop new technologies, foster innovation, provide aeronautical support, and develop applications.[9] FireSense will implement outreach and engagement efforts with the goal of community and coalition building, conducting fire regime studies and research, assessing hazards and risks, analytics, simulation, and the transition from research to operations, including pilot programs and demonstrations.[10]

Of particular note is that FireSense will facilitate collecting data and developing innovative, miniaturized, advanced sensors and models—to better detect wildfire risk, propagation, and impacts; predict fire spread—to enhance suppression and emergency response efforts and real-time resource optimization; and integrate remote sensing and modeling—to predict and mitigate wildfire impacts e.g., debris flows, degraded vegetation, as well as air and water quality. FireSense will also develop a comprehensive, integrated pre-, active-, and post-wildfire observing system with open-source tools to generate actionable information needed by stakeholders to make informed decisions. The program will include rapid aerial response to wildfires with diverse crewed and uncrewed observations, i.e., unmanned aerial systems.

NASA FIRMS Update

FIRMS has been a part of NASA's Land, Atmosphere Near real-time Capability for EOS (LANCE) since 2012.[11] At a global level, efforts are underway to ingest geostationary operational fire data from the Japanese Himawari, [Advanced Himawari Imager–Fire Surveillance Algorithm (AHI-FSA)], European Meteosat [FRP algorithm], and NOAA GOES-R [Fire Detection and Characterization (FDC) algorithm] series.

The U.S. Forest Service (USFS) approached NASA to develop FIRMS for northern North America (i.e., for the U.S. and Canada). The prototype was released in January 2021; planned next steps include ingesting real-time MODIS and VIIRS data and Landsat AF detections for robust fire characterization, useful for wildfire management.

Canadian WildFireSat Mission

In April 2022 the government of Canada awarded end-to-end funding to the Canadian Space Agency, Natural Resources Canada, and Environment and Climate Change Canada to develop a new wildfire satellite monitoring system known as WildFireSat.[12] The mission has a planned 2028 launch and a five-year mission duration, with the possibility of extension. Essential WildFireSat features include visible–near infrared (VIS-NIR) (200 m) and midwavelength infrared (MWIR)/long-wavelength IR (LWIR) [400 m] spectral bands, 30-minute data latency, and the capability to map actively burning fires to a resolution of 15 x 15 m. In addition to the NRT data delivery already discussed, the mission's fire monitoring capability includes AF perimeter and progression mapping, fire rate of spread (m/min) (when combined with VIIRS AF data), and NRT measurement of carbon emissions and smoke plume dynamics. As a part of the Phase-A mission configuration, two academic institutions were tasked with proposing a daily fire monitoring system, resulting in two different design concepts based on three-satellite and single-satellite systems, respectively. The three-satellite design was chosen based on advantages due to technical feasibility, data quality, modularity, and potential for graceful degradation and redundancy.

Committee on Earth Observation Satellites' Fire Updates

A comprehensive gap analysis for AF EO is ongoing as part of the Committee on Earth Observation Satellites' (CEOS) Disasters program. A CEOS pilot project on wildfires was added to the CEOS disasters program in March 2021. Its four major tasks are to conduct a detailed inventory and gap analysis of existing and proposed EO systems suitable for monitoring global active fires; conduct a detailed analysis of global stakeholders and end users of NRT AF EO data; define targeted user requirements for AF remote sensing systems for disaster mitigation applications; and propose a way forward in coordinating global wildfire

[9] To learn more about the background and establishment of FireSense, see *go.nasa.gov/3SGQ6Cb*.
[10] To initiate FireSense, NASA organized a Wildfire Stakeholder Engagement Workshop that took place May 3–4, 2022. A white paper summarizing the workshop outputs can be found at *nari.arc.nasa.gov/smdwildfire*.
[11] To learn more about FIRMS, see *go.nasa.gov/3RmrhdF*.
[12] To learn more about WildFireSat, see *asc-csa.gc.ca/eng/satellites/wildfiresat*.

monitoring activities. As part of this pilot program, user requirements for AF remote sensing will be identified, including a way to close existing and future fire information gaps. The project may also identify the needs of other aspects of wildfire EO (e.g., prefire and postfire monitoring). The project's outputs will be delivered in the next three years.

GCOS Fire Updates

The World Meteorological Organization's (WMO) Global Climate Observing System (GCOS) Implementation Plan for Fire Essential Climate Variables (ECV) is being finalized and subjected to review, including GOFC–GOLD Fire-IT member input. It includes the revision of the 2016 ECV requirements for AF, BA, and FRP products—in response to input provided from users of these products about their requirements. Proposed improvements for these products are under review by GCOS and will be finalized by the end of 2022. In addition, although a "combustion completeness" variable has been proposed, this is still in the research and development phase.

GOFC–GOLD Fire-IT members are also involved in documenting best-practice guidelines for AF, BA, and FRP measurements as a part of CEOS Land Product Validation (LPV) Protocols activity. The GOFC–GOLD Fire-IT members in attendance expressed an urgent need for these guidelines due to the proliferation of fire products, including those with little quality assessment and minimal validation.

GOFC–GOLD Regional Network Updates

A principal role for GOFC–GOLD is to provide a coordinating mechanism for national and regional activities. GOFC–GOLD has helped develop regional networks (RN) of data providers, brokers, and users—see **Figure 3**. These networks provide the key to sustained capability to improve the observing systems and ensuring that the data are being used effectively. GOFC–GOLD RNs remained active during the COVID pandemic, with nine different virtual meetings held in 2021. As the COVID pandemic eases and travel once again resumes, the different RNs plan a combination of in-person and virtual meetings and training events. Key highlights from the regional and national fire presentations are summarized below.

South/Southeast Asia

In 2020, at the height of the shutdowns resulting from the COVID pandemic, fire-related air pollution decreased over South/Southeast Asia. South Asian countries had an overall reduction of ~0.26 Tg of TPM emissions when compared to previous non-COVID years, and 0.14 Tg less than in 2019. Similarly, in Southeast Asian countries 2020 showed an overall reduction of ~1.11 Tg TPM emissions compared to previous non-COVID years and 1.75 Tg less than in 2019.

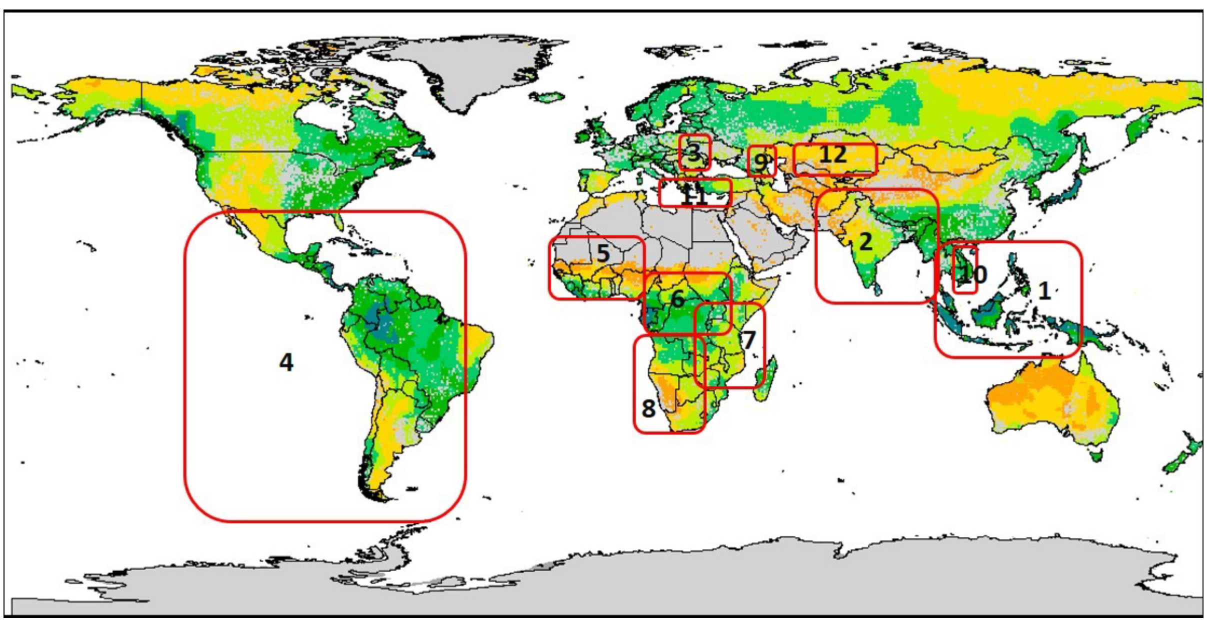


Figure 3. This map shows the currently active GOFC–GOLD Regional Networks (RNs), several of which are discussed here. The RNs (labeled as numbers on the Figure) include: 1. Southeast Asia Regional Research and Information Network (SEARRIN); 2. South Asia GOFC–GOLD Network [SAGN]; 3. South Central European Regional Information Network (SCERIN); 4. Red Latinoamericana deTeledeteccion e Incendios Forestales (RedLaTIF); 5.West African Regional Network (WARN); 6. Observatoire Satellital des Forets d'Afrique Central (OSFAC); 7. Miombo Network (MIOMBO); 8. Southern Africa Fire Network (SAFNET); 9. Caucasus Regional Information Network (CaucRIN); 10. Mekong Regional Information Network (MekRIN); 11. Mediterranean Regional Network (MedRIN); and 12. Central Asia Regional Information Network (CARIN). **Figure credit:** Krishna Vadrevu/MSFC

The Association of Southeast Asian Nations (ASEAN) agreement on transboundary haze pollution has been active in Southeast Asian countries since 2003. As a part of ASEAN and to address the fire pollution issues, the Meteorological Climatology and Geophysics Agency of Indonesia [Badan Meteorologi, Klimatologi, dan Geofisika (BMKG)] developed a decision-support system called Sistem Peringatan Kebakaran Hutan dan Lahan, or SPARTAN, which integrates satellite fire data from several sources and the Canadian fire-danger rating system and produces a fire-danger-rating map for the entire Southeast Asian region. Different training events are being conducted on the utilization of SPARTAN.[13]

The Center for International Forestry Research (CIFOR) is the leader on another project focusing on air pollution in Southeast Asian countries, the "Measurable Action for Haze-Free Sustainable Land Management in Southeast Asia Program." This is a five-year project (2019–2024) funded by the International Fund for Agricultural Development (IFAD) focused on reducing transboundary haze pollution and its impacts in Southeast Asia through enhanced regional coordination, making focused investments, applying knowledge, and managing results. ASEAN countries contribute data for this project, with some—but not all—related to fires, e.g., daily weather conditions and seasonal forecasts, El Niño and La Niña effect forecasts (global and regional), fire hotspot maps (global, regional, and national), haze maps, fire-danger rating (Fire Weather Index, or FWI), limited fire-management statistics, and national BA mapping—but for Indonesia only, as described below.

Indonesia's Directorate of Forest and Land Fire Control, which is part of the Ministry of Environment and Forestry, has been leading a country-level BA mapping effort using Landsat data. There was discussion of the results from the latest report, which highlights the results from 2000–2020. CIFOR plans to establish policy and guidance for BA mapping for the ASEAN countries.

Latin America

The Red Latinoamericana de Teledetección e Incendios Forestales (RedLaTIF) network focuses on Latin American countries, with priorities that include detecting, mapping, characterizing, and validating BAs, assessing post-fire severity, developing fire early-warning systems, and exploring links between land-cover dynamics and fire regimes. Multiple virtual webinars have been conducted during the past two years to promote technical capacity-building in the region.

[13] To learn more about the capabilities of SPARTAN, see *spartan.bmkg.go.id.*

Of concern to members of the group was that current operational systems do not fulfill user needs, which means that developing and tuning global algorithms and products for regional and local needs must be addressed. RedLaTIF researchers will continue to promote capacity building in association with academic institutions, and focus on local community needs, e.g., technology transfer and training.

RedLaTIF members gave a presentation that focused on efforts in Brazil. Two geostationary satellite instruments monitor fires over Brazil—ABI on the NOAA GOES-R series and the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) on the European Meteosat Second Generation (MSG)[14] series. Sun glint is a major factor that impairs daytime detection of vegetation fires with the 3.7–4.2 μm band in all satellites. A comparison of the number of fire pixels detected by the ten different satellites used by the Brazilian National Institute for Space Research's [Instituto Nacional de Pesquisas Espaciais (INPE)] wildfire monitoring program during October 2019 suggested that Suomi NPP's AF product detected the highest percentage of fires (35.4%), followed by NOAA-20's (33.6%), and GOES-16's (15.7%). All other satellites detected less than 4% of fires with MSG-03 showing the least detections (0.1%). Congruence analysis over Brazil for AFs detected by GOES-16 and by polar orbiting satellites (Terra, Aqua, Suomi NPP, and NOAA-20) for October 2019 using the current INPE algorithm for geostationary imagers, suggests that polar orbiter data reflect more fires than geostationary data, which suggests the need for more robust geostationary detection algorithms.

Southern Africa

The Miombo Network (MN) and Southern Africa Fire Network (SAFNet) are both located in southern Africa. The Miombo Network provides scientific information and policy guidance for Miombo forests across their range countries, with an emphasis on facilitating research and policy analysis to improve the benefits from the Miombo forest ecosystem and for human livelihood. The MN generates a newsletter that highlights research activities and opportunities, both across and outside the region. Members of the new MN steering committee will attend an August 4, 2022, Government of Mozambique meeting on "Sustainable Management of the Miombo Forests" to discuss the recent MN book *The Miombo Woodlands in a Changing Environment:*

[14] This should not be confused with MetOp–Second Generation (MetOp-SG) discussed earlier. The first eight Meteosat launches were considered "first generation." Four Meteosat Second Generation (MSG) launches took place from 2002–2015 (becoming known as Meteosat-8. -9, -10, and -11, respectively, after launch). The first Meteosat Third Generation (MTG) launch (to be renamed Meteosat-12) is planned for late 2022, with three more MTG launches to follow between 2025–2035 (to be renamed Meteosat-14, -15, and -17, respectively, after launch).

Securing the Resilience and Sustainability of People and Woodlands—published by Springer in 2020—that was released at the June 2021 MN meeting.

The SAFNet evolved from the MN in 1999 with an emphasis on fire monitoring, fire research, and applications, including in non-Miombo regions of southern Africa. The eleventh SAFNet meeting was held virtually in July 2021 with a focus on identifying regional fire projects that can help sustain the network. Resulting recommendations included seeking support for graduate students from the region to work on fire research tropics and to gain first-hand experience with managing fires and their impacts on people and ecosystems, providing refresher virtual courses on satellite fire information services to regional researchers and practitioners, and developing fire apps to reach younger and less scientifically literate audiences to raise awareness concerning fires, including their negative impacts and positive ecological benefits. Long-term collaboration between the MN and SAFNet is expected to continue, with joint research and response to calls on fire-related topics of mutual interest.

Mediterranean Region

The Mediterranean (MedRIN) network includes the Mediterranean countries of Europe, the Levant, and North Africa. MedRIN thematic priorities include land cover and land use change (LCLUC) and related impacts, hazards (e.g., fires, earthquakes, landslides, and floods), soil and water resource management, and climate change. Various meetings have been organized as part of the network's activities, starting with the kickoff meeting in Chania, Greece, in July 2018 and three subsequent meetings, held in March 2019 (in person), June 2021 (virtual), and February 2021 (virtual). The June 2021 meeting was a joint meeting with the South Central European Regional Informational Network (SCERIN) that focused on droughts, migration—due to recent regional conflicts—and the resulting population exodus into the Mediterranean and East-Central European regions.

The Greek Observatory of Forest Fires (gOFFi) focuses on developing products and services to increase wildfire preparedness and assess pre- and postfire environmental impacts. These include fuel-type mapping, midterm fire danger index, and BA mapping, all available through a WebGIS platform.

GOFC–GOLD Activities Down Under

While there is no formal GOFC–GOLD RN covering Australia and New Zealand, there were presentations that reported on fire-monitoring activities in these areas, as summarized below.

New Zealand

New Zealand's main firefighting and emergency services body, Fire and Emergency New Zealand (*fireandemergency.nz*), has been using an automated fire-growth and smoke-forecasting decision-support system to monitor and manage fires. The system integrates VIIRS and MODIS data with the fire growth prediction model and Weather Research and Forecasting System (WRF) model at 4-km (~2.5-mi) horizontal resolution. Research is underway on BA detection using 10-m (~33-ft) Sentinel-2 imagery, high-resolution aerial photography, and synthetic aperture radar (SAR) data from Copernicus Sentinel-1. The objective is to investigate the use of open-access satellite data to identify wildfire fuel types and augment a national land cover database (LCDB). Early results suggest that, given the correct amount and type of training data, machine-learning (ML) models can detect a range of expanded fuel classes. Sentinel-2 10-m data for New Zealand data provide an adequate spatial resolution for most purposes.

Australia

In Australia, ML methods are being used to predict wildfire fire ignition occurrences from lightning forecasts. Researchers studied the probability of wildfire ignition by lightning using ECMWF's lightning density forecast (average number of flashes over a specified time interval). A ML approach was used to define a predictive model for ignition, based on lightning forecasts and environmental conditions. The study used three different binary classifiers: a decision tree,[15] AdaBoost, and a Random Forest.[16] The results showed both the Random Forest and AdaBoost out-of-sample accuracy to be 78%. In addition, data provided by a Western Australia wildfire database allowed a comprehensive verification of over 145 lightning-ignited wildfires in regions of Australia during 2016, suggesting that in a minimum of 71% of the cases, the ML models correctly predicted the occurrence of ignition when a fire was actually initiated.

[15] A decision tree is a decision support tool that uses a tree-like model to evaluate decisions and their possible consequences. Decision trees incorporate all data and try to show all possible results.

[16] AdaBoost and Random Forest are the two most common types of ensemble models—a model that makes predictions based on a number of individual models. A helpful description of these two ensemble model types is found at *towardsdatascience.com/basic-ensemble-learning-random-forest-adaboost-gradient-boosting-step-by-step-explained-95d49d1e2725.*

Other Noteworthy Presentations

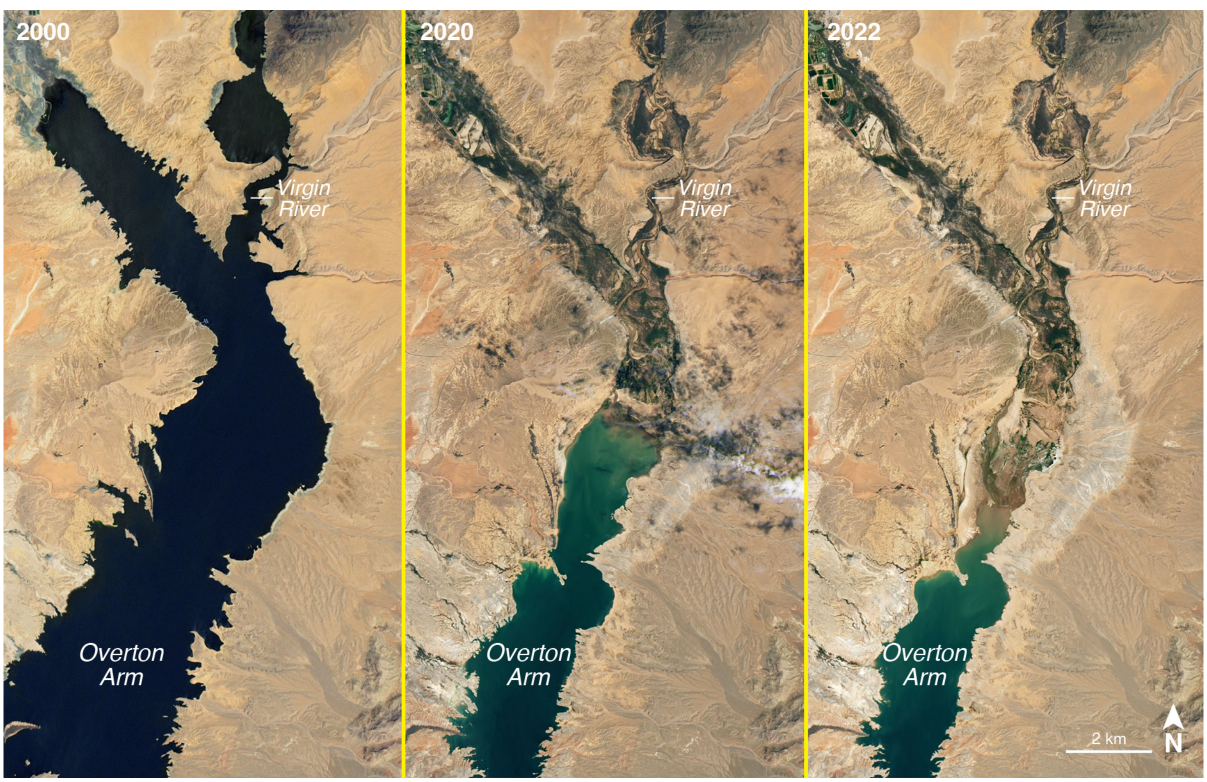
Earth observations can provide material evidence to allow formulating and implementing government policies and help determine their effectiveness. For example, in Punjab, India, a case study showed how policy-driven timing shifts in crop residue burning (CRB) worsen air quality and human health in North India. For the 2016 air quality crisis, modeling demonstrated that CRB was responsible for more than 40% of near-surface airborne $PM_{2.5}$. Thus, systems to collect, store, and process agricultural residues into biofuel are needed to curb air pollution.

Another presentation highlighted a robust association between medium-term exposure to smoke from landscape fires and child mortality in low-income and middle-income countries (LMICs). The five countries with the largest burden were the Democratic Republic of the Congo, Nigeria, Uganda, India, and Indonesia. The study assessed the burden of child mortality based on a representative exposure–response function specifically derived for landscape fire smoke exposure in LMICs for the first time.

Conclusion

The Fifth GWIS/GOFC–GOLD Fire-IT meeting served as a forum to exchange ideas and information from and with a diverse range of fire experts, the GOFC–GOLD Fire-IT members, and RN researchers. Attendees noted that several civilian space agencies are increasing their investment in wildfire observations and research: there is a growing need to share information on what is being done and to identify opportunities to coordinate across the various international activities. With increasing frequency and severity of fires, the group noted the importance of maintaining the GOFC–GOLD forum to strengthen the international community's collaboration and cooperation on understanding and managing wildfire. GWIS/GOFC–GOLD researchers emphasized the need for quality assurance and easy access to validated satellite-based fire products useful to address fire management and mitigation at the local level. In addition, meeting participants recommended increased capacity-building and training activities to advance fire science and the use of EO in different countries.

The next meeting is planned for summer 2023. Details will be posted when they are available. ■



Low Water Levels in Lake Mead. Continuing a 22-year downward trend, water levels in Lake Mead in the Southwestern U.S. stand at their lowest since April 1937—when the reservoir was still being filled for the first time. As of July 18, 2022, Lake Mead was at just 27% of capacity.

These three natural color images showing clear shrinkage over the past two decades use data from the Enhanced Thematic Mapper Plus (ETM+) on Landsat 7 from July 6, 2000 [left], the Operational Land Imager (OLI) on Landsat 8 from July 8, 2021 [center], and OLI on Landsat 8 from July 3, 2022 [right]. To learn more, see *earthobservatory.nasa.gov/images/150111/lake-mead-keeps-dropping*.

Image and partial text credit: *The Earth Observatory*

Summary of NASA's LANCE User Working Group Meeting

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Introduction

For over a decade, NASA's Land, Atmosphere Near-real-time Capability for EOS (LANCE) has been providing data within three hours of observation to a variety of time-sensitive applications users. LANCE is a virtual system that leverages 12 existing Earth Observing System (EOS) Data and Information Systems (EOSDIS) science processing systems and data archive elements, with an umbrella set of requirements to ensure consistency and coordination.[1] Data are currently available from 11 instruments, 10 of which are operated by NASA and/or the National Oceanic and Atmospheric Administration (NOAA), and one by the Japan Aerospace Exploration Agency (JAXA), which is part of the international Afternoon "A-Train" constellation. The LANCE instruments are listed in the **Table**, below.

NASA's Goddard Space Flight Center's (GSFC) Earth Science Data and Information Systems (ESDIS) Project manages LANCE, which is in turn steered by a User Working Group (UWG), representing the broader user community. The UWG is responsible for providing guidance and recommendations regarding LANCE systems, capabilities, and services. The LANCE UWG meets bi-annually to review the status of LANCE (including progress made on previous UWG recommendations) and potential new enhancements and upgrades. The most recent UWG meeting was held virtually May 3–4, 2022. In addition to the 10 (of 12) UWG members attending the virtual meeting, 55 others attending included LANCE data users, representatives from each of the LANCE elements, NASA Headquarters, and the ESDIS Project. This article summarizes the highlights of that meeting. To see the complete agenda and presentations visit *go.nasa.gov/3DoTxsX*

[1] To learn more about the history and accomplishments of LANCE, see "LANCE: A Decade of Achievement Providing Near Real-Time NASA Earth Observing Data," in the January–February 2020 issue of *The Earth Observer* [Volume 32, Issue 1, pp. 4–11—*go.nasa.gov/3BQCsW8*]. The LANCE architecture is summarized in Figures 2 and 3 on page 7 of that article—which were adapted from Figures on the Earthdata website at *go.nasa.gov/3Rswwsa*.

Table 1. List of instruments providing data for LANCE and the platform(s) on which they fly.

Instrument	Mission(s)
Advanced Topographic Laser Altimeter System (ATLAS)	Ice, Clouds, and land Elevation Satellite–2 (ICESat-2)
Atmospheric Infrared Sounder (AIRS)	Aqua
Lightning Imaging Sensor (LIS)	International Space Station
Measurement of Pollution in the Troposphere (MOPITT)	Terra
Microwave Limb Sounder (MLS)	Aura
Microwave Scanning Radiometer 2 (AMSR2)	Japan Aerospace Exploration Agency's (JAXA) Global Change Observation Mission–Water (GCOM-W) series
Moderate Resolution Imaging Spectroradiometer (MODIS)	Aqua and Terra
Multi-angle Imaging Spectroradiometer (MISR)	Terra
Ozone Monitoring Instrument (OMI)	Aura
Ozone Monitoring Profiler Suite (OMPS)	NASA–NOAA Suomi National Polar-orbiting Partnership (Suomi NPP)
Visible Infrared Imaging Radiometer Suite (VIIRS)	Suomi NPP, NOAA-20, and NOAA-21*

*NOAA-21 launched on November 10, 2022, While not yet providing data, it will soon, and is included here for completeness.

Opening Remarks

Karen Michael [GSFC—*ESDIS LANCE Manager*] opened the meeting. **Miguel Román** [Leidos—*Senior Director and Chief Scientist of Climate and Environment, LANCE UWG Chairperson,* and *MODIS Science Team Leader]* welcomed the attendees and set the stage for the meeting's primary theme by stressing the importance of data continuity as the community plans for the new Earth Systems Observatory (ESO) missions and prepares for decommissioning the EOS Flagship missions, Terra, Aqua, and Aura. The end of these missions will result in the loss of near-real-time (NRT) data from seven instruments currently contributing data to LANCE: MISR, MODIS, and MOPITT on Terra; AIRS and MODIS on Aqua; and MLS and OMI on Aura.[2] Thus, planning for continuity of these datasets is an immediate priority.

Overview of Open Source Science

Katie Baynes [NASA HQ—*Deputy Chief Science Officer*] began with an overview of the Science Mission Directorate's (SMD) strategy for data and computing, with the Transformation to Open Source Science (TOPS), and SMD's Science Data Policy 41/41A, which applies to all future SMD-funded efforts. She then reviewed the status of the NASA HQ Earth Science Division's (ESD) Commercial Smallsat Data Acquisition (CSDA) program. Baynes also provided an ESD perspective on the future of LANCE, favoring relaxing guidelines on data sources but with strict adherence to the "three hours from observation" rule.

NASA Headquarters Applied Sciences Program Perspective

David Green [NASA HQ, Applied Sciences Program (ASP)—*Program Manager of the Wildfire Management Program*] expressed ASP's concerns regarding continuity of NRT products after Terra, Aqua, and Aura are decommissioned. The Wildfire Management program is very dependent upon LANCE, particularly the Fire Information for Resource Management System (FIRMS). FIRMS relies heavily on NRT data from the MODIS instruments on Terra and Aqua. Green recommended the UWG support the development of a transition plan, which may require user training and capacity development. He also provided examples of other missions that were not initially intended to provide low-latency data, but due to considerable interest and demand are now actively exploring the feasibility. A prime example of this is the joint NASA–Indian Space Research Organisation (ISRO) Synthetic Aperture Radar (NISAR) mission. Green reported that there is now an Early Adopter initiative to prepare for the advent of NISAR and provide feedback to the NISAR team regarding the needs of their applications.

Continuity of Data Products in the Post EOS Flagship Era

As noted earlier, the EOS Flagship Missions (Terra, Aqua, and Aura) are all nearing the ends of their respective missions. The exact timing of the end of mission (EOM) is a subject of active discussion in the Earth Science community at this time. Numerous data products rely on the data flowing from these instruments, and scientists are working to secure the continuity of these important datasets, several of which are discussed below.

Robert Wolfe [GSFC—*Chief of the Terrestrial Information Systems Laboratory* and *Terra Deputy Project Scientist for Data*] provided a comprehensive presentation on the plans for decommissioning Terra (launched in 1999) and Aqua (launched in 2002), based primarily on presentations from the April 2022 MODIS Land Workshop. Terra's final inclination maneuver occurred in March 2020; the spacecraft is now drifting, expected to leave the constellation in October 2022.[3] Science data collection is expected to end in December 2023. Aqua will discontinue science data collection in August 2023. For land science activities, continuity with Aqua MODIS-PM observations will be provided by the Visible Infrared Imaging Radiometer Suite (VIIRS) on NASA/NOAA Suomi National Polar-orbiting Partnership (Suomi NPP), NOAA-20, and NOAA-21.[4] However, there are no U.S. observations planned that will provide continuity for Terra MODIS-AM observations.[5]

MODIS Land Products after Terra and Aqua

Wolfe also discussed options that would potentially provide MODIS-AM continuity through international cooperation—especially for land products. One possibility is to use data from the European Space Agency (ESA) Sentinel-3 missions, which have a 10:00 AM overpass and are planned to operate until 2031. The Sentinel-3 Sea and Land Surface Temperature Radiometer (SLSTR) instrument has a Fire Radiative Power Product that could be compared with the MODIS Active Fire product for potential use by

[2] All undefined acronyms used in this paragraph are either defined previously or in the **Table 1** on page 21.

[3] **UPDATE:** Terra's departure from the Morning Constellation has now taken place.

[4] The Joint Polar Satellite System–2 (JPSS-2) mission launched on November 10, 2022. JPSS-2 will be renamed NOAA-21 after launch and initial checkout.

[5] Terra was originally named EOS-AM, because its overpass time is 10:30 AM Mean Local Time (MLT) heading northward (10:30 PM MLT heading southward). Similarly. Aqua was orginally named EOS-PM because its overpass time is 1:30 PM MLT heading northward (1:30 AM MLT heading southward).

FIRMS.[6] The top of the atmosphere products from the Sentinel-3 SLSTR and Ocean and Land Color Instrument (OLCI) could be evaluated for use in an updated MODIS Corrective Reflectance algorithm.

Another option presented was to evaluate the EUMETSAT MetOp Second Generation (MetOp-SG) mission, which will include MetImage, a VIIRS-like instrument. The MetOp-SG series of six satellites will have a 9:30 AM overpass, and are planned for launch between 2024 and 2039.[7]

MODIS Land Science Team has made recommendations to NASA HQ to pursue both these avenues.

Global Satellite-based Flood Monitoring

Guy Schuman [ImageCat, Inc.] presented information on uses and users of MODIS and VIIRS daily Global Flood Maps. Such usage includes situational awareness; providing advisories, warnings and alerts; and impact assessments. Users include researchers as well as applications, like the United Nation's World Food Program, which relies on the data for analytics and operations. Schuman noted that—while the VIIRS NRT water mapping is very useful—MODIS is demonstrably better for flood mapping. Sentinel-3 instruments are also being considered to provide continuity with MODIS flood maps.

Fire Monitoring

Brad Quayle [U.S. Forest Service (USFS)] discussed the importance of FIRMS Global and FIRMS U.S./Canada as strategic tools used to increase situational awareness, inform resource allocation decisions, focus tactical-scale fire mapping assets, and inform the public. He described current and planned fire products from FIRMS. New imagery products include the Harmonized Landsat Sentinel-2 (HLS) False Color products, useful for detecting burned areas. Later in the meeting, **Brian Freitag** [NASA's Marshall Space Flight Center (MSFC)] provided more insight into the HLS products and described how the dynamic false-color composite has been made available in FIRMS. The HLS products provide global land-surface reflectance

[6] To learn more about potential fire monitoring capabilities of SLSTR, see the section of the article "Summary of the Fifth Joint GWIS/GOFC–GOLD Fire-IT Meeting" on page 12 of this issue.

[7] To learn more about MetImage and MetOp-SG (and WildFireSat mentioned on the next page) see page 12 of the "Summary of the GWIS/GOFC–GOLD Fire-IT Meeting" in this issue.

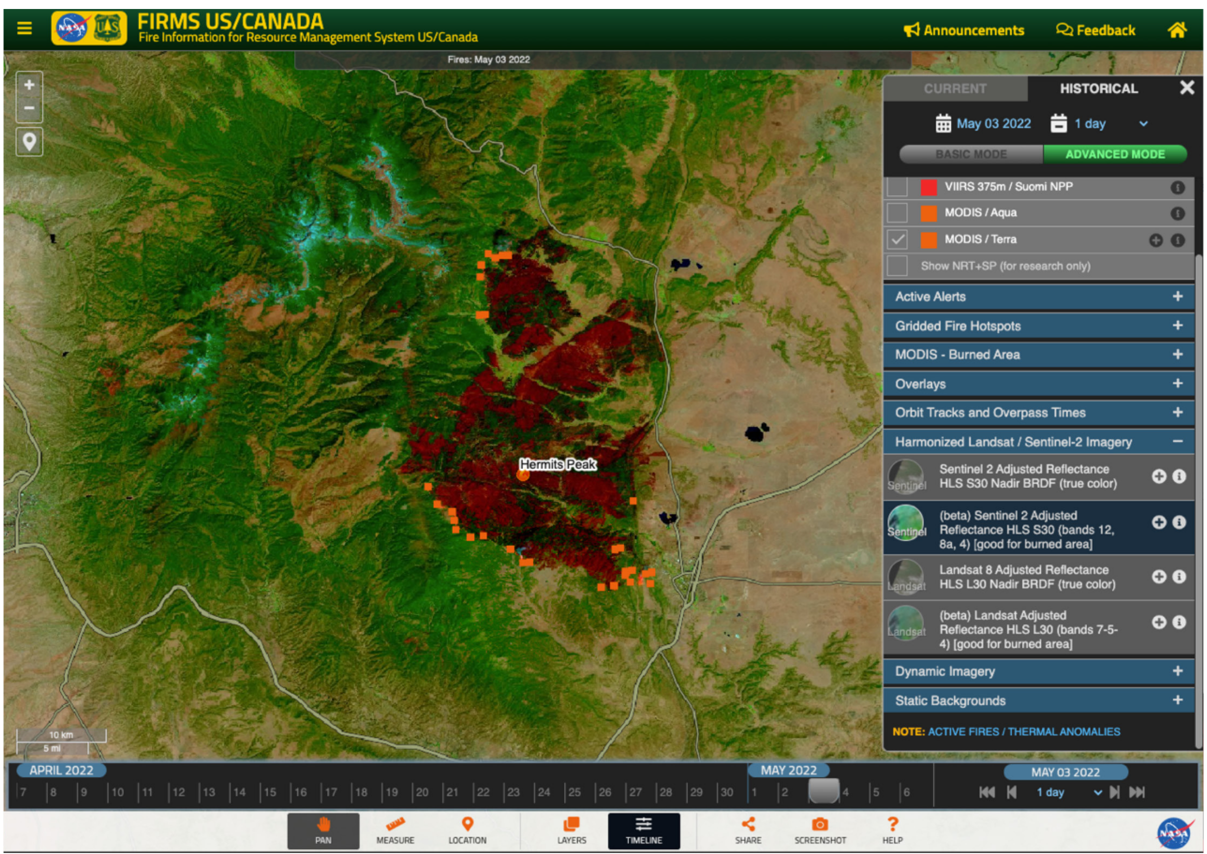

Figure. A screenshot from Land, Atmosphere Near-real-time Capability for EOS (LANCE) Fire Information for Resource Management System (FIRMS) U.S./Canada displaying the Copernicus Sentinel-2 Adjusted Reflectance Harmonized Landsat Sentinel (HLS) using a combination of Bands 12, 8a, and 4. It shows the Hermit's Peak Fire in New Mexico (U.S.) as captured on May 3, 2022. In this image the burned areas appear in brick red and are overlaid with active-fire pixels from MODIS and VIIRS. (To view in FIRMS see *go.nasa.gov/382r4Ml*.) **Image credit:** LANCE FIRMS U.S./Canada coverage (excluding Antarctica) every 2–4 days with a spatial resolution of 30 m (~98 ft). Freitag showed some examples of recent fire events.

USFS has also been working with the University of Wisconsin to incorporate real-time direct readout data for FIRMS U.S./Canada. **Liam Gumley** [University of Wisconsin–Madison, Space Science and Engineering Center (SSEC)] presented results of this effort. The team has developed a system to receive, decode, and process MODIS and VIIRS data to produce active-fire products for the continental U.S. within 60 seconds of direct broadcast. The software processes microgranules through Level-1 (geolocation, calibration) to Level-2 active fire products. They are currently using X-band antennas in Madison, WI, Honolulu, HI, Hampton, VA, Monterey, CA, and Mayaguez, PR, with plans to add other antennas in the future. Gumley described the workflow process, and reported that active-fire location information are provided to LANCE/FIRMS within ~25 seconds for MODIS and ~50 seconds for VIIRS.

Regarding continuity in the post-Terra/Aqua era, the USFS is also exploring Sentinel-3 SLSTR data and future MetOp-SG MetImage data from EUMETSAT. For the PM crossing, they are reaching out to the Canadian Space Agency, seeking access to their future WildFireSat microsat constellation, scheduled for launch in 2028.

Future Missions and Potential Opportunities for LANCE

A number of new missions on the horizon will potentially contribute to future LANCE activities. Earth System Observatory (ESO) missions, described below, are placing emphasis on applications support and data latency.

Atmosphere Observing System

Emily Berndt [MSFC] gave an overview of the Atmosphere Observing System (AOS), one of the ESO missions coming from the 2017 Earth Science Decadal Survey[8] recommendations for targeted observables of aerosols and cloud convection and precipitation. AOS will potentially produce five "first evers": global observation of convective vertical air motion; global profiles of aerosol properties (absorption, type, size, number); colocated dynamics, cloud, and precipitation microphysics, aerosol characteristics, and radiation; evolution of cloud and aerosol processes; and diurnal variability of cloud and aerosol profiles. The AOS Applications Team is charged with ensuring that applications are considered to the greatest extent possible in mission design and implementation. AOS applications thematic areas include: weather, air quality, and climate modeling and forecasting; disaster monitoring and modeling; water resources; infrastructure and development; and public health and ecosystem health. While latency requirements are still evolving, the AOS team has accepted requirements for 75% of radiometer data to be downlinked in less than 3 hours after acquisition; 85% available in less than 4 hours; and 95–100% available in less than 5–6 hours.

Surface Biology and Geology

Christine Lee [NASA/Jet Propulsion Laboratory] provided an overview of the Surface Biology and Geology (SBG) mission, also part of the ESO. The SBG mission will consist of two primary platforms: SBG Heat, with a wide-swath Thermal Infrared (TIR) imager and a Visible and Near-Infrared (VNIR) camera; and SBG Light, with a wide-swath Visible to Short-Wave Infrared (VSWIR) spectrometer. A third VSWIR SmallSat is also envisioned. SGB Applications sectors include agriculture, food security, and surface water management; water quality and coastal zone conservation; wildfire risk and recovery; disasters and natural hazards; and geology applications. Lee cited a recent research article, "Systematic Integration of Applications into the SBG Earth Mission Architecture Study,"[9] as evidence of the benefits and commitment to emphasizing the importance of applications from the beginning of the mission. Currently, two different latency "buckets" have been identified for SBG products:

- *Routine low-latency products*—Less than 24 hours for Level-2 and higher products. This time constraint is driven by Agriculture and Food Sector demands); and
- Event-driven low-latency product—Less than 6 hours. This lower latency is needed for hazard response.

TROPICS

Vince Leslie [Massachusetts Institute of Technology (MIT), Lincoln Labs] reported on recent developments with the Time Restored Observations of Precipitation Structure and Storm Intensity with a Constellation of SmallSats (TROPICS) mission. TROPICS is a constellation of six CubeSats, each carrying a passive microwave radiometer, to be launched by three Astra launch vehicles.[10] The primary purpose of TROPICS is science

[8] The official title is, "Thriving on Our Changing Planet: A Decadal Strategy for Earth Observations from Space," and it can be viewed at and downloaded from *nap.nationalacademies.org/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth*.

[9] This study was published in the March 2022 issue of *Journal of Geophysical Resesarch: Biogeosciences* [**Volume 137, Issue 4**—*doi.org/10.1029/2021JG006720*].

[10] **UPDATE:** Regrettably, the launch of the first two TROPICS SmallSats failed in June 2022. However, the TROPICS missions can still be accomplished with four satellites. NASA is currently exploring options for launching the four remaining TROPICS satellites.

research, but based on interest and funding by NOAA, a low-latency demonstration was conducted from April 25–29, 2022. The baseline ground system supported three passes per day, with a data latency of 6–13 hours. By increasing the number of contacts to 18 per day and making software improvements in the Mission Operations Center (MOC) and the Level-1 radiance algorithm, the demonstration team succeeded in reducing the average data latency to one hour. Preliminary analyses indicate that the low latency for the constellation is very manageable—but funding availability is not yet clear.

Satellite Needs Working Group

Cerese Albers [NASA HQ—*Earth Science Data Systems Program Executive*] presented a summary of the Satellite Needs Working Group (SNWG), which was created in 2016 by the U.S. Group on Earth Observations (USGEO) to identify high-priority, unmet needs for satellite data within U.S. civil federal departments and agencies. The SNWG formulates and conducts a biannual survey to capture, document, and communicate satellite Earth-observing needs to NASA, which then conducts a detailed assessment of the expressed needs, and responds with proposed solutions to multiple, high-priority needs. For each SNWG report cycle, solutions are provided: there were 5 solutions provided for Cycle 2016, 9 for Cycle 2018, and 14 for Cycle 2020. Solutions are carried as a proposal for congressional funding in the president's budget. Four of the 2016 solutions are operational (including HLS), and the fifth awaits the launch of NISAR. Two of the 2018 solutions are operational, with the remainder in various stages of implementation. The SNWG Management Office espouses and fosters Open Source Science,[11] including a program of dedicated stakeholder engagement.

In addition to new missions, the SNWG will consider adding new products to LANCE on a case-by-case basis, as they did in 2021 when they requested five new, low-latency datasets from the Ice, Cloud, and land Elevation Satellite–2 (ICESat-2) team. These additional quick-look (QL) datasets provide sea ice, water extent, and vegetation information approximately 72 hours after a satellite observation—much more quickly than the typical 45-day processing period required for ICESat-2 standard datasets.

Artificial Intelligence and Machine Learning for NRT Data

Manil Maskey [MSFC] provided a brief overview of artificial intelligence (AI) and deep learning using advanced algorithms such as neural networks. Asking the right questions with good data is critical for AI to be useful. The Earth Science Data Systems Program has adopted an AI strategy focused on challenges to improve the efficiency of the data systems operations, e.g., providing means to search through petabytes of data quickly and provide seemless access to information discovery while keeping the open data policies. Maskey gave examples of the complicated problems that can be solved using AI including leveraging machine learning models to automatically detect Earth science events, e.g., smoke plumes. Once these machine learning models have been developed they can be employed by users to find similar events from large data archives enabling them to get to the data quicker.

Identifying a NRT Path to Assimilate Geostationary Aerosol Data

Arlindo da Silva [GSFC, Global Modeling and Assimilation Office] made a presentation on the urgent need to augment aerosol data from polar-orbiting satellites with data from geostationary satellites. Currently, MODIS Dark Target/Deep Blue products are assimilated in the Goddard Earth Observing System (GEOS) model NRT system, and similar products from VIIRS are in the process of being assimilated. Dark Target algorithm tests are underway with data from the Advanced Baseline Imager (ABI) on the Geostationary Operational Environmental Satellite (GOES)-R series satellites, and the Advanced Himawari Instrument (AHI) on Japan's Himawari-8. Results using data from both these geostationary missions (which obtain full disc images of parts of the Earth every ten minutes) will complement—and look consistent with—outputs from MODIS and VIIRS (which have two overpasses of a particular location each day).

The nominal locations of the Advanced Imagers (e.g., ABI and AHI) will provide almost global coverage in the so-called *GEO-ring*. Da Silva pointed out that having regular observations throughout the day (Earth's full disk being imaged every 10 minutes) to complement MODIS and VIIRS (twice-daily observations) will enable scientists to better monitor the diurnal cycle. Da Silva solicited feedback from the international Cooperative for Aerosol Prediction (ICAP), with an overwhelmingly positive result: there was a strong consensus about the urgent need to add NRT geostationary aerosol data. Da Silva requested the help of the LANCE UWG in making this happen. Miguel Román agreed that geostationary data would be beneficial, and the group recommended that da Silva submit a formal LANCE enhancement request that can be forwarded to NASA HQ; he agreed to do so.

[11] To learn more about Open Source Science at NASA, see "Open Source Science: The NASA Earth Science Perspective" in the September–October 2022 issue of *The Earth Observer* [**Volume 33**, **Issue 5**, pp. 5–9—*eospso.nasa.gov/sites/default/files/eo_pdfs/Sep%20-%20Oct%202021%20color%20508.pdf#page=5*].

STREAM for Water Monitoring

Nima Pahlevan [GSFC/Science Systems and Applications, Inc.] gave a presentation on the Satellite-based Analysis Tool for Rapid Evaluation of Aquatic EnvironMents, or STREAM, which is a system to improve water-quality monitoring and engage with end users and the United Nations Environment Programme. The STREAM prototype uses the FIRMS interface as the framework, and was established to complement the multiagency (Environmental Protection Agency, USGS, NOAA, and NASA) Cyanobacteria Assessment Network (CyAN). STREAM identifies water-quality hotspots to trigger field studies, which in turn can result in water-quality advisories or preventative action. STREAM uses data from NASA–USGS Landsat 8 and 9, European Copernicus Sentinel 2A and B, and the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Data Analysis System [SeaDAS] to generate Level-2 products. In-house ML models generate water-quality products, which are rigorously validated. Currently, relevant data are accessible to water authorities in Peru and Uruguay, and data are available for the San Francisco Bay. Next steps are to expand and improve STREAM to provide other products (e.g., water clarity), expand coverage, and possibly leverage commercial data as an input. A formal LANCE enhancement request to achieve these steps is currently under consideration.

Amazon Web Services Ground Station Study

Matt Bialas [Element 84] presented an update on Phase 3 of an ongoing proof-of-concept study to evaluate the Amazon Web Services (AWS) Ground Station as a Service (GSaaS) as an option for NRT data acquisition and processing. The study used direct-broadcast VIIRS data from Suomi NPP and NOAA-20, and MODIS data from Aqua. The goal was to minimize latency in providing products to FIRMS and the NASA Disasters Mapping Portal. Response time was greatly improved from 24–30 minutes to 10–13 minutes. Bialas noted that antenna usage time accounted for nearly 98% of the costs.

Metrics, Feedback, and Updates

This section reports on metrics related to LANCE, feedback on LANCE received from the NASA Applied Sciences community, and updates from Worldview and GIBS and LANCE MODIS products.

LANCE Metrics

Diane Davies [GSFC, ESDIS Project—*LANCE Operations Manager*] presented a summary of LANCE performance and data usage metrics. Overall, data latencies are within the three-hour requirement, with occasional exceptions. The number of users continues to increase steadily. MODIS data (from both Terra and Aqua) continue to make up nearly 80% of total data downloaded, with a small increase in VIIRS data downloads. Davies used Google Analytics to show the number of visits to LANCE webpages and FIRMS. Peaks occurred in conjunction with major events, e.g., large wildfires, the invasion of Ukraine. FIRMS continues to be used to track the invasion, see fires set during the war, and verify events on the ground. Numerous media outlets have used and cited FIRMS and imagery from the Worldview mapping interface.[12]

Feedback on LANCE Products from the Applied Sciences Community

Tian Yao [GSFC ASP—*LANCE Liaison*] presented feedback on LANCE from three ASP surveys. Respondents from NASA SERVIR[13] and Applied Remote Sensing Training (ARSET) teams emphasized the value of GIS-friendly formats, with GeoTIFF being favored. Latin America and Caribbean (LAC) users access LANCE data via Worldview and the NASA Disasters Mapping Portal. They use the VIIRS night-time lights, MODIS/VIIRS active-fire data, and products related to volcanic eruptions. For disaster response, one-to-three-hour latency is sufficient, but less than one hour would be ideal for forest fires. Volcanic Ash Advisory Centers (VAACs) use LANCE products to detect ash clouds, differentiate between ash and sulfur dioxide, and provide imagery to fill gaps in GOES-17 data. Lower latency (e.g., 15 minutes) accessibility to data from geostationary satellites would be welcome.

Update on Worldview and GIBS

Ryan Boller [GSFC—*ESDIS Data Visualization Lead*] provided an update on Worldview and Global Image Browse Services (GIBS), for which numerous new and updated features have been added since the last UWG meeting. An example is the Progressive Web Application that allows full-screen mode on phones and local caching for faster load times. He provided an update on the Granule/Swath Visualization Prototype, requested by the UWG and nearing readiness for evaluation. Boller reported on the progress made in transitioning GIBS to the Earthdata cloud, which will provide more opportunities for dynamically visualizing data through custom color palettes, custom band combinations, and custom visualization of specific parameters. This new "maps with knobs" feature should be particularly beneficial, with access to new and upcoming higher-volume data sets, such as from the Harmonized Landsat and Sentinel-2 (HLS), Surface Water and Ocean Topography (SWOT), and NISAR missions.

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[12] To learn more about Worldview and its capabilities, see *worldview.earthdata.nasa.gov.*

[13] SERVIR is not an acronym; it's a Spanish verb that means "to serve."

Updates on MODIS Products

Sadashiva Devadiga [GSFC—*MODIS/VIIRS Adaptive Processing System* (*MODAPS) Lead*] reported on the status of MODAPS and the MODIS Flood Map product (MCDWD), a project funded through the Research Opportunities in Space and Earth Science (ROSES—*2020:A.33*). While the beta version of MCDWD has been available publicly since January 2021, work continues to generate the product in the operational system to more readily test improvements, process historical data, and create an archive version. Spectral mapping between MODIS and VIIRS has started to enable a continuity product from VIIRS.

Crystal Schaaf [University of Maryland, Baltimore County] provided status reports on the MODIS Bidirectional Reflectance Distribution Function (BRDF), Nadir BRDF-Adjusted Reflectances (NBAR), and Albedo Products in LANCE for MODIS Collection 6.1, which are now available from LANCE. Daily Collection 2 NRT VIIRS Albedo, BRDF, and NBAR products will also be available soon. Schaaf recommended that the LANCE team encourage the use of the extensive flags provided in the system, particularly for snow or no-snow retrievals.

Conclusion

LANCE is currently transitioning to a new operational phase. Until recently the goal of LANCE was to deliver all data within three hours of satellite overpass. This pattern changed with the addition of the ICESat-2 QL products. LANCE will diversify further as it plans for the new ESO missions and identifies new sources of data to provide continuity for the flagship EOS missions, which will be decommissioned. There is a need to engage with new missions to encourage continued NRT data availability for operational decision makers.

LANCE continues to attain good visibility within the Applied Sciences Program as more end users are involved in responding to extreme events. The participants identified several action items for the LANCE Team to pursue between now and the next meeting, including exploring synergies between NASA's new Wildfire program and LANCE, facilitating the acquisition of NRT aerosol data from geosynchronous platforms, and identifying new data sources beyond Terra, Aqua, and Aura. The next meeting will be held virtually on November 9–10, 2022. Details will be posted at *go.nasa.gov/3UzAPDX.* ■

Hosting the World Cup Leads to Development in Qatar. In November and December 2022, thirty-two international teams and more than one million football fans (soccer in the U.S.) converged on the tiny (population 2.6 million) Persian Gulf nation of Qatar for the 2022 World Cup.

The Operational Land Imager-2 (OLI-2) on Landsat 9 captured this natural-color image of the capital city of Doha on November 13, 2022. Development radiates outward from Doha's historic city center along a series of ring roads, and includes extensive artificial land built up to accommodate airport and port facilities, as well as entirely human-made islands that have become hubs of residential and commercial activity.

The black with white outline numbers show where the eight stadiums that have been built to host World Cup games. Seven have been built since 2010, when Qatar was awarded the event. The stadiums are all within a 54-km (33-mi) radius of Doha. To learn more—and to see close-up images of each stadium—see *earthobservatory.nasa.gov/images/150630/stadium-city-qatar*.

Image and partial text credit: *The Earth Observatory*

Summary of the Eighth ABoVE Science Team Meeting

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Introduction

The eighth annual Arctic-Boreal Vulnerability Experiment (ABoVE) Science Team Meeting (STM) was held May 9–12, 2022, both in person at the University of Alaska, Fairbanks, and online. The meeting was held in conjunction with a Research to Operations (R2O) Workshop with the Alaska land management community that took place May 12–13, 2022, at the same location. Several members of the ABoVE Science Team (ST) stayed on to participate in this meeting—see "Research to Operations Workshop with Alaska Land Management Community" on page 30 for details about this latter meeting.

ABoVE is a NASA Terrestrial Ecology Program field campaign that is a large-scale study of environmental change and its implications for social–ecological systems in Alaska and western Canada. ABoVE's science objectives are broadly focused on gaining a better understanding of the vulnerability and resilience of Arctic and boreal ecosystems to environmental change in western North America and providing the scientific basis for informed decision making to guide societal responses at local to international levels.

The ABoVE field campaign is notionally divided into three phases of roughly equal length over the approximately 10-year study period: Phase 1 (2015–2018) focused on ecosystem dynamics, Phase 2 (2017–2022) expanded to include ecosystem services and modeling objectives, and Phase 3 (beginning in 2023) will focus on analyzing and synthesizing results from the first two phases. The Phase 2 ABoVE ST was comprised of 66 NASA-funded Terrestrial Ecology projects, 35 NASA-funded projects from other NASA programs, and 29 *affiliated projects*—which are funded by non-NASA sources but are highly relevant to the ABoVE campaign, for a total ST membership of more than 850 people. Phase 3 of the campaign will add 20 new projects, which will further increase the size of the ST.

As is becoming increasingly common in the "post-pandemic" world, this meeting was a true hybrid event with about equal participation in person and online: 109 registered in-person attendees and 105 registered virtual attendees—see **Photo 1**, below. In addition to NASA-funded researchers, attendees included representatives from other U.S. federal agencies, territorial

Photo 1. Group photo of the ABoVE STM in-person attendees and some of the 109 virtual attendees. **Photo credit:** Sarah Dutton

and provincial governments in Canada, and Canadian federal agencies—such as the Canadian Forest Service (CFS) and Polar Knowledge Canada—as collaborators and partners.

Meeting Overview

The agenda included a mix of presentations from thematic working groups; sessions with partners, collaborators, and local decision makers affiliated with ABoVE projects and the overall ST; planning activities for the summer 2022 ABoVE airborne campaign; parallel sessions featuring short presentations of research results from individual projects (and poster sessions for those attending in person); invited presentations that synthesize ABoVE research to date; and breakout sessions for working-group discussions and planning. For those attending in person, the Carbon Cycle & Ecosystems Office (CCEO) also organized optional field trips to nearby locations of interest: the U.S. Army Corps of Engineers' Cold Regions Research and Engineering Laboratory's Permafrost Tunnel, the Alaska Satellite Facility, and the Alaska State Division of Forestry's Fairbanks Office and Operations Center—see **Photo 2**, below.

The focus of the meeting was to present and discuss ABoVE Phase 2 research results and to pave the way for the start of Phase 3 in 2023. Summaries of specific parts of the meeting appear below. The full meeting agenda, along with uploaded presentations and recordings of all plenary sessions is available at *above.nasa.gov/meeting_2022/agenda.html*.

Welcoming Remarks

Peter Griffith [NASA's Goddard Space Flight Center (GSFC)/Science Systems and Applications, Inc. (SSAI)—*CCEO Chief Scientist*] and **Scott Goetz** [Northern Arizona University—*ABoVE ST Lead*] gave opening remarks. Goetz touched on the goals and objectives of ABoVE and the STM, focusing on the shift from finishing the Phase 2 project to beginning the Phase 3 projects. He also highlighted recent ABoVE-published research. In particular, Goetz noted that there have been almost 450 published papers from the approximately 130 projects affiliated with ABoVE.

NASA Headquarters Update

There was an update from NASA's Headquarters (HQ) with **Hank Margolis** [*Terrestrial Ecology Program Manager*] and **Mike Falkowski** [*Terrestrial Ecology Program Scientist*] speaking. Margolis welcomed all attendees and mentioned how happy he was to be able to attend the meeting in person. Falkowski expressed his gratitude for the ability to attend remotely. Both conveyed their excitement about hearing updates from Phase 2 projects and the ST working groups, noting the importance of their successes for the upcoming transition to ABoVE Phase 3.

Photo 2. This grouping includes a photo from each of the three "field trips" that took place during the Eighth ABoVE STM. They include: a look inside the U.S. Army Corps of Engineers' Cold Regions Research and Engineering Laboratory's Permafrost Tunnel [*left*], the downlink antenna outside the Alaska Satellite Facility [center], and a row of chainsaws staged for firefighter usage at the Alaska State Division of Forestry's Fairbanks Office and Operations Center [*right*]. **Photo credit:** Elizabeth Hoy

Research to Operations Workshop with the Alaska Land Management Community

The ABoVE Science Team Meeting was held in conjunction with a Research to Operations (R2O) workshop titled "Using Remotely Sensed Data in Fire and Resource Management." Several members of the ABoVE ST stayed on to participate in the R2O workshop that immediately followed the STM, which was co-organized with the Alaska Fire Science Consortium (AFSC). Participants discussed progress made in integrating remote sensing data into land and fire management based on goals set during a prior 2017 AFSC remote sensing workshop. This in-depth R2O workshop focused on using remotely sensed data and products in operational and decision-making settings and offered a space for ABoVE scientists and the fire- and resource-management communities to work together directly.

The workshop began with agency remarks from local agency leaders in Alaska including **Tom Heinlein** [Bureau of Land Management], **Helge Eng** [Division of Forestry], and ABoVE Science Team Leader, **Scott Goetz**. Additionally, the workshop participants discussed barriers and next steps for developing NASA research and data products that address operational needs in the areas of soil moisture; vegetation; and smoke, emissions, and combustion estimates from fire. ABoVE scientists and land managers gave plenary presentations throughout the workshop, and then breakout groups were formed to further the discussion and interaction.

Some participants took a field trip to the Alaska State Division of Forestry's Fairbanks Office and Operations Center which showcased the extensive wildfire response planning done by the fire management community and provided context into potential NASA data products most needed when responding to an incident—see the rightmost picture in Photo 2 on page 29 and the four photos below. Over the next few months, AFSC will develop a report to discuss meeting outcomes and provide actionable recommendations for the future.

Tour of the at Alaska State Division of Forestry's Fairbanks Office and Operations Center including (*clockwise from top left*) the firefighter dispatch facility, food coolers, firetrucks, and fire protection clothing staged for firefighter response. **Photo credit:** Elizabeth Hoy

Photo 3. Alison York [AFSC], **Darcy Peter** [WCRC], and **Jim Lawler** [NPS] discuss successful engagement and collaboration strategies with ABoVE ST attendees during the panel discussion. **Photo credit:** Leanne Kendig

Panel Discussion and Small Group Discussions Highlight Partnerships and Collaboration

A substantial portion of the first day was devoted to updating and reconnecting with ABoVE partners, data-product end users, and relevant decision makers in the ABoVE study domain.

The morning panel discussion on collaboration and engagement began with a presentation by **Darcy Peter** [Woodwell Climate Research Center (WCRC), now at Northern Latitudes Partnership (NLP)] on guiding principles for working in northern communities, with a specific focus on Indigenous peoples. Because a significant portion of the population in the ABoVE study domain is Indigenous, the guiding principles are helpful to enabling the ST to meaningfully engage and collaborate with these communities. Other panelists included **Jim Lawler** [National Park Service (NPS)], **Hannah-Marie Garcia** [NLP], and **Alison York** [Alaska Fire Science Consortium (AFSC)]—see **Photo 3**, above. The NLP and AFSC are important boundary organizations in the region that facilitate the availability of ABoVE data products to end users such as land-management agencies like NPS. The speakers discussed their perspectives on collaboration regarding research approaches and implementation, as well as more detailed needs for specific data products.

Later in the meeting five smaller discussion groups convened to further discuss topics that came up in the first morning's panel discussion, including strategies for integrating decision makers into ABoVE research. **Randi Jandt** [AFSC], **Robbie Hember** [British Columbia Ministry of Forests], **Kevin Smith** [Ducks Unlimited], **David Lutz** [Dartmouth College], and **Jim Lawler** [NPS] led the discussion groups, which focused on specific topics such as fire management, forestry planning, and wildlife conservation.

ABoVE Programmatic Updates

The ST also had the opportunity to hear programmatic updates from official ABoVE partners. **Peter Thornton** [U.S. Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL)] presented information on DOE's Next-Generation Ecosystem Experiment–Arctic (NGEE–Arctic). **Misha Warbanski** [Polar Knowledge Canada (POLAR)] provided an update on recent POLAR research and funding activities. **Jason Edwards** [CFS] gave a presentation describing the current activities of CFS, which included their participation in the new Canadian National Adaptation Strategy. **Andrew Applejohn** [Government of Northwest Territories (GNWT)] informed the ST about GNWT research priorities, permitting procedures, and status of programs given the ongoing COVID-19 pandemic. **Sabrina Kinsella** [Government of Yukon] gave an overview of Yukon initiatives, partnerships, and research facilities. **Christopher Baird** [Battelle] described field activities and opportunities for collaboration with the National Ecological Observatory Network (NEON) in Alaska.

Plenary Presentations Focus on Synthesis and Identifying Knowledge Gaps

During the invited plenary presentations, the speakers discussed campaign results from the more than 330 research papers and over 200 data products developed to date. Each speaker was charged with presenting both a retrospective synthesis or current state of knowledge and a forward-looking assessment for ways to address remaining knowledge gaps. The invited presentations are summarized in **Table 1** on page 32. The full presentations are available at the URL listed in the Introduction to this article.

Progress Updates from Thematic Working Groups

The ABoVE ST has several thematic working groups that meet throughout the year, so the STM is an opportunity for each group to share progress with the entire team. Planners also built time into the agenda for the working groups to have crosscutting discussions to discuss further synthesis activities. **Table 2** on page 32 shows the thematic working groups and crosscutting breakout sessions from the meeting.

Table 1. Invited Presentation Topics and Speakers at 2022 ABoVE Science Team Meeting

Presentation Title	Presenter [Affiliation]
Top-down Thaw, Thermokarst, and Ecotype Relationship	**Thomas Douglas** [U.S. Army Cold Regions Research and Engineering Laboratory–Alaska]
Biotoxicological Risks and Hazards of a Thawing Arctic	**Kimberley Miner** [NASA/Jet Propulsion Laboratory (JPL)]
The Permafrost Dynamics Observatory: Remotely Sensed Active Layer Thickness and Soil Moisture	**Kevin Schaefer** [University of Colorado's National Snow and Ice Data Center]
Wildlife and Snowscapes	**Natalie Boelman** [Columbia University's Lamont–Doherty Earth Observatory] and **Laura Prugh** [University of Washington]
Biomass from Lidar	**Paul Montesano** [NASA's Goddard Space Flight Center (GSFC)] and **Laura Duncanson** [University of Maryland]
Biomass from Synthetic Aperture Radar	**Paul Siqueira** [University of Massachusetts–Amherst]
Arctic–Boreal Carbon Budgets: Reducing Uncertainty Through Integrated Monitoring	**Jennifer Watts** [WCRC]
Arctic–Boreal Modeling	**Helene Genet** [University of Alaska Fairbanks]
Processing Options for ABoVE Data at Oak Ridge National Laboratory's (ORNL) Distributed Active Archive Center (DAAC)	**Bruce Wilson** [ORNL]
Processing Options for ABoVE Data at GSFC's NASA Center for Climate Simulation (NCCS)	**Jim Shute** [GSFC]

Table 2. List of Thematic Working Groups and Cross-Cutting Discussion Groups at 2022 ABoVE STM

<table>
<tr><th>Thematic Working Groups, Presenters [Affiliation]</th><th>Crosscutting Breakout Session Foci, Presenters [Affiliation]</th></tr>
<tr><td>Carbon Dynamics
Abhishek Chatterjee [JPL]</td><td rowspan="2">Carbon Dynamics + Wetlands
Clayton Elder [JPL]</td></tr>
<tr><td>Wetlands
David Butman [University of Washington]</td></tr>
<tr><td>Vegetation Dynamics
Howie Epstein [University of Virginia]
Brendan Rogers [WCRC]</td><td rowspan="2">Vegetation Dynamics and Spectral Imaging
Brendan Rogers [WCRC]</td></tr>
<tr><td>Spectral Imaging
Fred Huemmrich [GSFC/University of Maryland Baltimore County]</td></tr>
<tr><td>Fire Disturbance
Nancy French [Michigan Technical Research Institute (MTRI)]</td><td rowspan="2">Fire and Insect Disturbance
Nancy French [MTRI]</td></tr>
<tr><td>Multi-Disturbance
Adrianna Foster [National Center for Atmospheric Research]</td></tr>
<tr><td>Hydrology and Permafrost
John Kimball [University of Montana]</td><td>Hydrology and Permafrost
John Kimball [University of Montana]</td></tr>
<tr><td>Modeling
Joshua Fisher [Chapman University]</td><td>Not Applicable</td></tr>
</table>

Individual Project Reports and Poster Sessions Highlight Early-Career Participants

Representatives from 57 individual projects presented short presentations in parallel, hybrid Research Highlights sessions, and poster sessions (for those attending in person). The parallel sessions were organized around the following scientific themes that closely align with the Thematic Working Group themes presented in Table 2: Carbon Dynamics; Vegetation Dynamics and Structure; Hydrology and Permafrost; Modeling; Fire Disturbance and Wildlife; and High-Performance Computing in High Latitudes. Early-career researchers and students were particularly encouraged to participate in these sessions. Several attendees served as moderators for sessions, and early-career presenters could volunteer to receive formal feedback on presentations by more senior participants via an online form.

The CCEO also arranged for mentor/mentee matchups, pairing both in-person and virtual early-career attendees with mentors matching their research and career interests as closely as practicable. Overall early-career attendance included 41 undergraduate and graduate students, 26 postdocs, and 52 early-career researchers (defined as less than 10 years since receiving their final degree).

Conclusion

The ABoVE STM was a successful meeting that offered the opportunity for the ST to update others on individual project progress, discuss with end users and decision makers strategies for meaningful collaboration, evaluate the achievements of Phases 1 and 2 of the ABoVE field campaign, assess remaining research gaps that will inform Phase 3 work, and generally allow for socializing and engagement among ST members. The hybrid components of the meeting allowed for meaningful participation from remote participants. In a post-meeting evaluation offered by the CCEO the respondents reported feeling that the hybrid aspects were successful.

As the support office for the ABoVE ST, the CCEO has organized and run all eight ABoVE STMs, including two virtual meetings conducted in 2020 and 2021. Prior to the pandemic, the CCEO was already creating online agendas with uploaded presentations that were accessible to all both during and after the STM. This eighth meeting was the first time the CCEO implemented a hybrid meeting approach. Its success hinged on the combination of technical expertise of CCEO staff combined with the exceptional facilities and audiovisual and information technology support offered by the meeting hosts at the University of Alaska Fairbanks.

Looking forward, while the CCEO is generally planning on more in-person meetings for the ABoVE ST, it hopes to retain some hybrid elements to allow for remote participation, increasing future accessibility and engagement of the ST with each other and relevant end users and decision makers. As ABoVE enters its third and final Phase in 2023, the ST will build on the successful research to date that has advanced our understanding of the multidimensional processes shaping terrestrial ecosystem changes underway in the Arctic–Boreal region, contributing to both process-level understanding and prognostic modeling. ■

Deep Concern About Food Security in Eastern Africa

Michael Carlowicz, NASA's Goddard Space Flight Center, michael.j.carlowicz@nasa.gov

EDITOR'S NOTE: This following has been adapted from an article on *The Earth Observatory* website. The original appears at *go.nasa.gov/3McjL4c*. Numerous references and resources are listed there.

The rains have failed in Eastern Africa for four consecutive seasons. That has not happened in 40 years of satellite records. Scientists and aid agencies are now alerting the world to an unprecedented level of food insecurity in 2022 for Ethiopia, Kenya, and Somalia. With forecasts suggesting the next rainy season will also be inadequate, climate and agriculture experts are advising governments and relief agencies to expect a significant need for food assistance.

According to a July 29, 2022, report from the Intergovernmental Authority on Development (IGAD) Climate Prediction and Applications Center's [ICPAC] Food Security and Nutrition Working Group,[1] the worst drought in 70 years has left more than 16 million people across the Horn of Africa coping with a shortage of drinking water. Yields of key crops are down for the third year in a row, milk production is in decline, and more than nine million livestock animals have died or been culled due to a lack of water and suitable forage land. At the same time, regional conflicts, COVID-19, locusts, and the Ukraine War have caused price spikes and shortages of basic commodities. An estimated 18–21 million people now "face high levels of acute food insecurity" in Ethiopia, Kenya, and Somalia, the working group noted.

Tropical countries within the Horn of Africa tend to have two rainy seasons: the October, November, and December (OND) *short rains* and the March, April, and May (MAM) *long rains* (which sometimes extend to August in some areas). The 2020 and 2021 OND rainfall was substantially below normal, and the 2021 MAM season was also drier than normal. Then the 2022 MAM season brought the lowest rainfall on record for much of the region. At the same time, the region has endured extremely warm air temperatures that desiccate soils and evaporate already diminished water supplies. **Figure 1** shows how rainfall in March, April, and May 2022 compared to the long-term average accumulation.

Newly planted seeds and young seedlings are highly dependent on moisture near the surface (0–6 cm, or 0–2.4 in). Root zone moisture (down to 1 m, or ~3.3 ft) is critical for long term crop growth: As plants grow and sink roots, they are sustained by moisture in deeper layers of the soil.

[1] This working group is cochaired by ICPAC and the United Nation's Food and Agricultural Organization. To view a summary of the report and to download the full report, visit *icpac.net/fsnwg/fsnwg-drought-special-report-29-july-2022.*

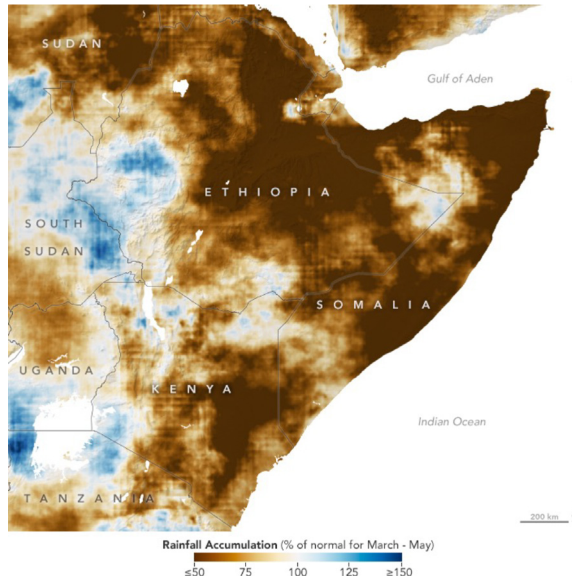

Figure 1. This map—based on observations from the Climate Hazard Center (CHC) InfraRed Precipitation with Stations [CHIRPS] dataset—shows how rainfall in March, April, and May 2022 compares to long-term average accumulation. Areas in dark brown were well below the average rainfall for the time of year, with many areas more than 50% below normal. **Image credit:** Lauren Dauphin/NASA's Goddard Space Flight Center (GSFC)/Science Systems and Application, Inc. (SSAI)

The Horn of Africa is especially prone to drought, so the Famine Early Warning System Network (FEWS NET)[2] and related agriculture and climate teams have invested significant research and modeling time into trying to predict rainfall patterns there. Scientists who study climate and weather *teleconnections*—i.e., how a change in atmospheric conditions somewhere on the globe can impact weather thousands of miles away—note that human-induced climate warming in the western Pacific, and a now-likely third year of La Niña conditions are contributing to the current drought. The La Niña cooling of the eastern tropical Pacific and the warming of the western Pacific disrupts weather patterns all over the world.

In a forecast released on August 16,[3] the FEWS NET agroclimatology team wrote: "Sea surface temperature

[2] The NASA FEWS NET Land Data Assimilation System [FLDAS] team generates and analyzes data on moisture at the land surface and in the top few centimeters of soil to show existing conditions and to predict them for upcoming months so that farmers and agriculture agencies can prepare for deficits or surpluses. Two animations produced using FLDAS data appear in the original version of this article at the URL listed at the top of this article.

[3] This forecast can be viewed at *blog.chc.ucsb.edu/?p=1219.*

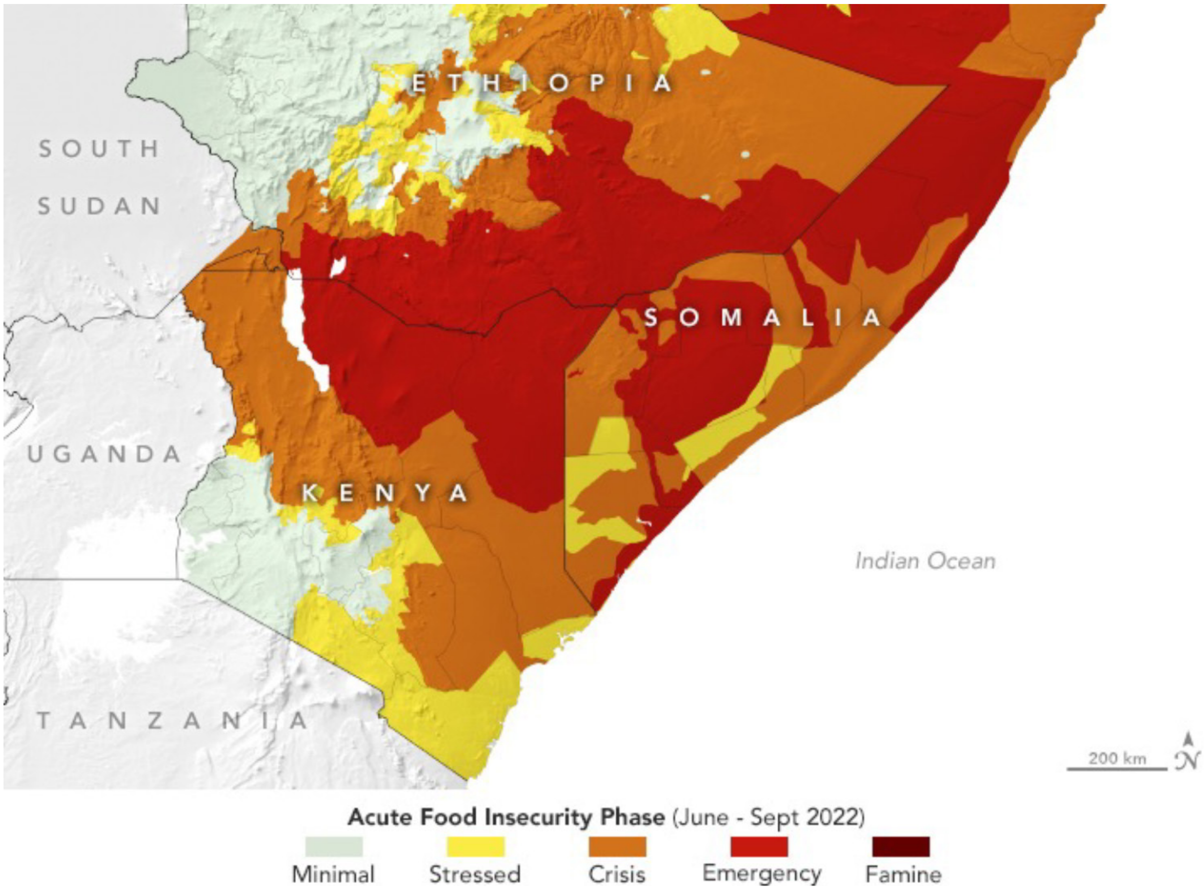

Figure 2. The map above, based on a data analysis by FEWS NET, shows the current levels of food insecurity across Ethiopia, Kenya, and Somalia. To describe the degree of insecurity, FEWS NET analysts use the Integrated Food Security Phase Classification, which is a standard used by the humanitarian assistance community. **Image credit**: Lauren Dauphin/GSFC/SSAI

predictions indicate a perfect ocean for drought. There is a very high probability of both strong Indian Ocean Dipole and West Pacific Gradient conditions, and hence it is very likely that the eastern Horn of Africa will experience very poor rains and very dry soil moisture and streamflow conditions in October–November–December." This would constitute an unprecedented fifth season of drought.

The successive rainfall deficits in Eastern Africa since 2020 have had a cumulative effect: smaller crop harvests and shortages of forage; depleted water supplies for people and animals; and weakened and depleted livestock herds. While reducing food and water sources, the drought also makes it hard for citizens to earn a living from their crops and herds. On top of that, the region has not fully recovered from the losses of a deep drought in 2016–17.[4]

According to the 1996 World Food Summit: "*Food security* exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life." **Figure 2** shows the current levels of food insecurity in the nations of Eastern Africa.[5] There is concern that another failed rainy season in late 2022 could push the region closer to catastrophe. According to the Food Security and Nutrition Working Group, more than 560,000 children were treated for severe malnutrition between January and June 2022. If conditions continue to decline, 23 million to 26 million people could face high levels of acute food insecurity by February 2023, and 6.5 million children are projected to suffer from acute malnutrition. ■

[4] *The Earth Observatory* reported on this drought at the time. To learn more, see *earthobservatory.nasa.gov/images/89735/food-shortages-in-the-greater-horn-of-africa*.

[5] For further discussion of the dimensions that follow from this widely accepted definition, see *fao.org/fileadmin/templates/faoitaly/documents/pdf/pdf_Food_Security_Cocept_Note.pdf*.

NASA Data on Plant 'Sweating' Could Help Predict Wildfire Severity

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

A new study uses data from the ECOSTRESS instrument onboard the International Space Station to better understand why some parts of a wildfire burn more intensely than others—potential indicators of fire risk.

Even in drought-stricken California, not all areas face the same degree of wildfire risk. A recent study featuring data from NASA's ECOsystem and Spaceborne Thermal Radiometer Experiment on Space Station, or ECOSTRESS mission found relationships between the intensity of a wildfire and the water stress in plants measured in the months before the blaze. The correlations weren't just a matter of dry plants burning more than hydrated ones; some areas where vegetation had sufficient water burned more severely, possibly because fires had more fuel to consume.

The research, led by scientists at NASA/Jet Propulsion Laboratory, draws on plant water-use data collected by ECOSTRESS.[1] The instrument measures the temperature of plants as they heat up when they run out of water. For this study, researchers focused on data collected during portions of 2019 and early 2020 over six areas—three in the Southern California mountains and three in the Sierra Nevada—that were subsequently scorched by wildfires.

Other research has shown that wildfire season across the Western U.S. is starting earlier in the year and increasing in length and severity. In California—a state with 33 million acres (13 million hectares) of forests, much of it managed by federal, state, and local agencies—detailed insights on the relationship between wildfire and the availability of water to vegetation could help fire-management officials identify not just whether an area will likely catch fire, but how serious the damage will be if it does.

"We are in an intense megadrought—the worst in 1200 years—and it's creating conditions for more catastrophic fires," said study co-author **Christine Lee** [JPL]. "Datasets like those from ECOSTRESS will be critical for advancing science and can provide information to support those who are responding to climate-change crises."

[1] These findings were published in a recent paper in *Global Ecology and Biogeography* published on May 16, 2022, found at *doi.org/10.1111/geb.13526*. To learn more details and to download the paper, visit *onlinelibrary.wiley.com/doi/abs/10.1111/geb.13526*.

Comparing the ECOSTRESS data with separate post-fire satellite imagery, researchers found that the rate at which plants release water by "sweating"—through a process known as *evapotranspiration*—as well as how efficiently they use water for photosynthesis, can help predict whether subsequent wildfires are more intense or less intense. Both these measurements are indicators of whether a plant community is getting enough water or is under stress from lack of it.

"We were trying to understand what drives differences in why some areas have severe burns and other areas don't," said lead author **Madeleine Pascolini–Campbell** [JPL]. "The results show how crucial water stress is for predicting which areas burn the most and why it's important to monitor vegetation in these regions."

Tracking Plant Stress

Like humans, plants struggle to function when they're too hot. And in much the same way that sweating helps humans stay cool, plants rely on evapotranspiration to regulate their temperature. Evapotranspiration combines the rate at which plants lose water as it evaporates from the soil and by transpiration, in which they release water through openings in their leaves, called *stomates*. To avoid losing too much water, plants start closing their stomates if they get too dry.

"As a result, [the plants] start to heat up because they don't have the benefit of 'sweating' anymore," Lee said. "With ECOSTRESS, we can observe these really fine changes in temperature, which are used to understand changes in evapotranspiration and water-use efficiency."

In general, slower evapotranspiration and lower efficiency signal that plants are water-stressed. Higher values indicate that plants are getting enough water.

ECOSTRESS tracks evapotranspiration via a high-resolution thermal radiometer that can measure the temperature of patches of Earth's surface as small as 130 x 230 ft (40 x 70 m).

High Versus Low Stress

The study found that water-stress-related variables, along with elevation, were dominant predictors of burn severity in areas struck by three Southern California wildfires in 2020: the Bobcat Fire in the Angeles

Photo. Smoke rises from the Bobcat Fire, which burned more than 115,000 acres (46,539 hectares) in Southern California's San Gabriel Mountains in 2020. In the months before the fire, NASA's ECOSTRESS passed over the area onboard the International Space Station, collecting data on plant water use. **Photo credit:** NASA

National Forest (see **Photo,** next page), along with the Apple and El Dorado fires in the San Bernardino National Forest.

According to Pascolini-Campbell, whether higher or lower stress predicted more severe burning depended on the primary type of vegetation in an area. For example, stressed pine forests tended to burn more severely, suggesting that drier conditions made trees more flammable. Meanwhile, in grasslands, lower stress tended to correlate with more burn damage, a possible indication that robust vegetation growth produced more fuel, resulting in more intense blazes. And in the Sierra Nevada regions burned by the Creek Fire, the Sequoia Complex Fire, and the North Complex Fire, results showed weaker relationships between pre-fire stress and burn severity. The study authors hypothesize that variables not captured in the analysis—e.g., wind or other weather conditions—were more influential in those burn areas.

Supporting Decision-Makers

The study comes as NASA is ramping up efforts to mobilize its technology, expertise, and resources to study wildfires. The agency in May announced the formation of NASA Wildland FireSense,[2] an initiative aimed at bringing together experts from different disciplines, along with advanced technology and analytical tools, to develop approaches that can inform and guide fire management decision-makers.

The importance of tools such as ECOSTRESS, which is scheduled to operate until September 2023, will grow as climate change drives greater wildfire risk across the Western U.S., Pascolini-Campbell said. "It's a high-priority region for using these types of studies to see which areas are the most vulnerable," she added. ■

[2] To learn more about FireSense, see *appliedsciences.nasa.gov/our-impact/news/nasa-makes-firesense*. FireSense is also discussed in the "Summary of the Fifth Joint GWIS/GOFC–GOLD Fire-IT Meeting" on page 12 of this issue.

How Scientists Used Acoustic Soundscapes and NASA Satellite Data to Assess the Health of the Amazon Rainforest

Erica McNamee, NASA's Goddard Space Flight Center, erica.s.mcnamee@nasa.gov

From space, parts of the Amazon rainforest that have previously been logged or burned may look fully recovered with a healthy, lush, and green canopy. They may seem to be places buzzing with activity and full of sounds. But inside the rainforest the animal life may tell a different story of damage to their environment through a quieter soundscape.

Scientists from NASA's Goddard Space Flight Center (GSFC), and the University of Maryland, College Park (UMD), investigated how the acoustics of a forest can be a cost-effective indicator of its health—see **Figure**, below.

Danielle Rappaport, [Amazon Investor Coalition—*Cofounder* (see **Photo**, on page 39)][1] has been the leader of this research since 2016; at that time, she was a doctoral student at UMD. She and her team combined acoustic data collected under the forest canopy with tree height measurements from aircraft flights and space-based observations of logging or fires from the joint NASA–U.S. Geological Survey Landsat satellites. Landsat is a long-running partnership between NASA and the U.S. Geological Survey.

In forests that were burned multiple times, recordings of animal noises were quieter than in intact forest locations, leaving gaps in the soundscape and indicating that species that had been present before were now gone. As Rappaport ventured into these previously burned parts of the rainforest to place the recorders for the scientific measurements, she said she could feel the differences.

"I've been working with tropical forests all my professional life," Rappaport said. "I've never quite been to a forest that was this devastated. It's something that you can smell, you can hear, it's everywhere."

On the first day of trekking through a forest that had been burned five times throughout the study period, Rappaport's field assistant quit—albeit temporarily— due to the oppressive nature of the environment. The environment was harsher in forests that had been burned several times, Rappaport said. The forest undergrowth was thick and difficult to navigate, and insects such as sweat bees surrounded her. However, these

[1]The Amazon Investor Coalition is a global learning and investment platform that unites philanthropies and private investors with governments, nonprofits, and allies to increase forest-friendly economic development and the rule of law across the Amazon region. Learn more at *amazoninvestor.org*.

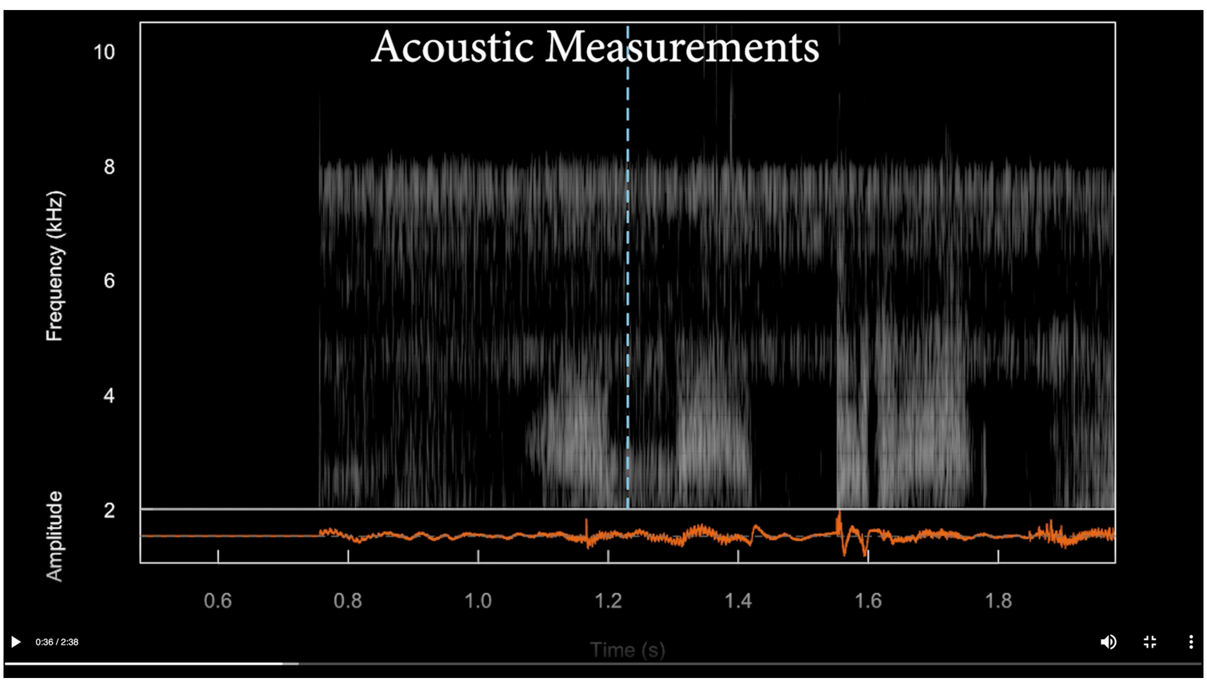

Figure. From space, parts of the Amazon rainforest that have previously been logged or burned may look lush and green, like a place buzzing with activity and full of sounds. But inside the rainforest, the animal life may tell a different story, of a harsh environment and a quieter soundscape. This still was taken from a video clip that describes this experiment, which can be viewed at *svs.gsfc.nasa.gov/14198*. **Image credit:** NASA's Goddard Space Flight Center

Photo. Scientist Danielle Rappaport is using a combination of satellite data and acoustic recordings to study the health of the Amazon. **Photo credit:** Danielle Rappaport

on-the-ground differences in the animal environment aren't observable when forests are measured from space, where the regrown canopy appears almost as green and complete as before the fires.

Instead of choosing specific times of day to target acoustic signatures of well-known species, Rappaport and her team chose to place and leave recorders in degraded forests for extended periods to gather a fuller, species-inclusive repertoire of sound. When analyzed together, these recordings revealed unique ecological fingerprints, or soundscapes. Species of frogs, insects, birds, and primates each occupy sound space in different ways—ways that enable biodiversity and ecological systems to be analyzed without scientists being physically present.

"You can think of the animal soundscape as an orchestra," Rappaport said. "The flutes occupy a different time of day and a different frequency band than the oboes."

Her team developed a new way to quantify forest health by analyzing soundscapes with a network theory approach. This means that by using the digital soundscape as a whole—i.e., hearing the music from the whole orchestra—Rappaport's team could understand the relationship between the level of impacts and the community of species—i.e., the character and quality of the individual instruments playing—without requiring all the species to be identified.

"It's one more step towards understanding the sound community without needing to know which individual species are there because we're starting to listen for them in ways that help us connect the coordinated production of sound, even if we don't know who's making the noise," said **Doug Morton** [GSFC], who was Rappaport's PhD advisor.

Knowing where to place the recorders, and how to interpret the diversity of soundscapes, required additional data from lidar measurements taken between 2013 and 2016 and the past 33 years of Landsat satellite records.

"Our ability to analyze decades of history through the Landsat data record provided a strong backbone to this work," Rappaport said.

The Landsat program, which marked its fiftieth anniversary in space this July,[2] allowed the scientists to see back in time. The scientists created a timeline of Amazon forest cover for the past three decades and used the history of forest degradation to determine where to place the recorders. With these data, the team sampled sounds from locations with varying levels of fire and logging activity.

Lidar measurements helped to explain the diversity of soundscapes by providing a three-dimensional representation of the forest's canopy. Airplanes flew over the forested areas, collecting tree height data that were used to help determine the layers of the forest between the canopy and the ground.

"That three-dimensional picture still carries a memory of some of those historic disturbances," Morton said.

These three quantitative datasets layered together helped Rappaport and her team better understand the ecosystem structure of Amazon forests impacted by human activity.

They found that repeatedly burned forests had less biodiversity than forests that were logged once. For example, with each additional forest fire, the soundscape becomes quieter. After logging, the forest soundscape suggested a capacity to recover animal diversity.

Rappaport and her team hope this new technique will lead to new understanding of forest biodiversity that is threatened by fires and logging, and about the relationship between biodiversity and carbon stored in Amazon forests over time. Soundscapes provide a relatively cost-efficient and rapid means of estimating levels of biodiversity in complex and generally species-rich tropical environments.

"Sound data add a new dimension to our understanding of the Amazon," Morton said. "I'm fascinated by what we still have to learn." ■

[2] To learn more, see *nasa.gov/feature/goddard/2022/landsat-legacy-nasa-usgs-program-observing-earth-from-space-turns-50*.

NASA Earth Science in the News

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

***Listening to the Amazon: NASA Reveals that "Recovered" Area May Not Have Healed as Much as We Thought**, August 17, *natureworldnews.com*.

Previously logged or burned areas of the Amazon rainforest may appear fully healed from space, with a robust, lush, and green canopy. They could appear to be busy areas with a lot of noise. The animal life, however, may reveal a contrasting tale of environmental harm inside the jungle through a quieter soundscape. Small trees growing up in conditions of drought may be the future of an Amazon rainforest that is drought-resistant, according to a new study. Researchers at the University of Maryland, College Park (UMD) and NASA's Goddard Space Flight Center (GSFC) looked at the possibility of using a forest's acoustics as a low-cost way to assess its health. Beginning in 2016, this study was directed by Danielle Rappaport, a doctorate candidate at UMD and cofounder of the Amazon Investor Coalition. She and her colleagues coupled acoustic data gathered beneath the forest canopy with measures of tree height obtained from airplane flights and satellite-based views of logging or fires made by Landsat. Animal noise recordings from burnt woods were quieter than those from intact forest areas, revealing gaps in the soundscape and indicating that species that had previously been there were now extinct. Rappaport claimed she could feel the differences as she entered these once burnt regions of the jungle to set up the recorders for the scientific observations—when forests are surveyed from space, the regrown canopy seems as green and full as before the fires, masking these variations in the animal ecology that are present on the ground. Rappaport and her colleagues decided to set and leave recorders in degraded woods for extended periods to acquire a larger, species-inclusive sound repertoire instead of focusing on certain times of day to target the acoustic signatures of well-known species. The researchers used lidar measurements obtained between 2013 and 2016 and from 33 years of Landsat satellite data, to help them determine where to position the recorders and how to interpret the variety of soundscapes. These recordings, when evaluated collectively, showed distinctive ecological soundscapes. Frog, bug, bird, and primate species all utilize sound space in distinctive ways that allow researchers to study ecological systems and biodiversity without being physically there. Rappaport suggested imagining the animal soundscape as an orchestra. "The flutes occupy a distinct time of day and a different frequency range than the oboes." Her team used a network theory technique to analyze soundscapes to create a brand-new way to measure forest health. This implies that Rappaport's team may comprehend the link between the number of effects and the community of species—i.e., the nature and quality of the instruments performing—by using the digital soundscape as a whole, i.e., the symphonic music, without needing to identify every species. "We're beginning to listen for them in ways that help us connect the joint production of sound, even if we don't know who's making the noise," said Rappaport's doctoral advisor, **Doug Morton** [GSFC—*Earth Scientist*]. "It's one more step toward understanding the sound community without needing to know which individual species are there," he added.

***What Plant Sweat Can Tell Us about Wildfires**, August 23, *gizmodo.com*. The way plants sweat could be a valuable tool in helping us predict how wildfires behave, according to a recent study published in *Global Ecology and Biogeography* by researchers at NASA/Jet Propulsion Laboratory. The temperatures of plants can tell us a lot about their health and the health of the ecosystems they live in. Under normal conditions, plants take in water through their roots and release it into the atmosphere through tiny pores in their leaves, a process known as evapotranspiration. But if the plants are under stress—especially if the weather is hotter and drier than usual—they'll retain more water, which increases their temperature. "It's a similar mechanism to humans sweating to cool down," explained **Madeleine Pascolini-Campbell** [NASA/JPL] and lead author of the study. "If plants aren't able to release water, that ends up with them heating up." The study was possible thanks to an instrument attached to the International Space Station called ECOSTRESS—a cute moniker for ECOsystem and Spaceborne Thermal Radiometer Experiment on Space Station. "It's basically a giant thermometer," said Pascolini-Campbell. "It takes measurements of the temperature of the Earth's surface, including plants." The ECOSTRESS instrument, which astronauts installed in 2018, is notable because of its specificity: It can obtain very high spatial resolution images "about the size of a soccer field," Pascolini-Campbell noted, and passes over the same region of Earth once every couple of days, providing frequent and focused observations of plant temperatures over relatively short periods of time. The NASA researchers wanted to see if the plants' levels of evapotranspiration could correlate with areas burned in California's

2020 wildfire season, a record-breaking summer that saw some 10,000 fires burn more than 4.3 million acres. They looked at data from six areas in Southern California and the Sierra Nevada Mountains that were badly damaged in the 2020 season, comparing ECOSTRESS measurements from the months before the fires as well as satellite imagery taken after the fires. Overall, the study found definite relationships between plant temperature and wildfire severity. In some regions, plants that were under more heat stress tended to be in areas with more intense burns. However, there were some important nuances in the data, given the diversity of the ecosystems at play. "Some areas, such as pine forests in the Sierra Nevada, if they were more stressed, that corresponded to them having more severe burning. But in some other areas that had different types of land cover, such as grasslands, the less-stressed vegetation had higher burn," Pascolini-Campbell said. The researchers hypothesized that in some ecosystems, like grasslands, less-stressed vegetation could actually grow more plentifully and ultimately provide more fuel for a fire. Pescolini-Campbell added, "We're seeing these kinds of nuanced relationships that really depended on the type of vegetation present." As the West's historic drought drags on and climate change makes wildfires even more intense and unpredictable, any data that can help predict fire patterns are invaluable. Pascolini-Campbell said she and her team hope to use ECOSTRESS data to study how plant sweat can foreshadow wildfire behavior in other areas of the U.S., like Oregon. "These kinds of datasets are really important and can potentially be used to predict fire severity for other regions, too," she said.

**See News Story on same topic in this issue*

High Tech Weather Sensors Built in Pasadena at JPL Capture Vital Data on Hurricane Ian, September 29, *pasadenanow.com*. Two recently launched instruments that were designed and built at NASA's Jet Propulsion Laboratory (JPL) to provide forecasters data on weather over the open ocean captured images of Hurricane Ian on September 27 as the storm approached Cuba on its way north toward the U.S. mainland. The Compact Ocean Wind Vector Radiometer (COWVR) and Temporal Experiment for Storms and Tropical Systems (TEMPEST) instruments observe the planet's atmosphere and surface from aboard the International Space Station (ISS). COWVR measures natural microwave emissions over the ocean and is about the size of a minifridge. The magnitude of the emissions increases with the amount of rain in the atmosphere, and the strongest rain produces the strongest microwave emissions. TEMPEST—comparable in size to a cereal box—tracks microwaves at a much shorter wavelength, allowing it to see ice particles within the hurricane's cloudy regions that are thrust into the upper atmosphere by the storm. The ISS passed in low Earth orbit over the Caribbean Sea at about 12:30 AM Eastern Daylight Time (EDT)—shortly before Ian made landfall in Cuba's Pinar del Rio province at 4:30 AM EDT, according to the National Hurricane Center. At that time, it was a Category 3 hurricane—with estimated wind speeds of 125 mph (205 kph). The **Figure** below combines microwave emissions measurements from both COWVR and TEMPEST obtained during that overpass. COWVR and TEMPEST sent the data back to Earth in a direct stream via NASA's Tracking and Data Relay Satellite (TDRS) constellation. The data were then processed at JPL and made available to forecasters less than two hours after collection. Data from the instruments are being used by government and university weather forecasters and scientists. The mission will inform the development of future space-based weather sensors, with scientists working on mission concepts that would take advantage of the low-cost microwave sensor technologies to study long-standing questions, such as how heat from the ocean fuels global weather patterns.

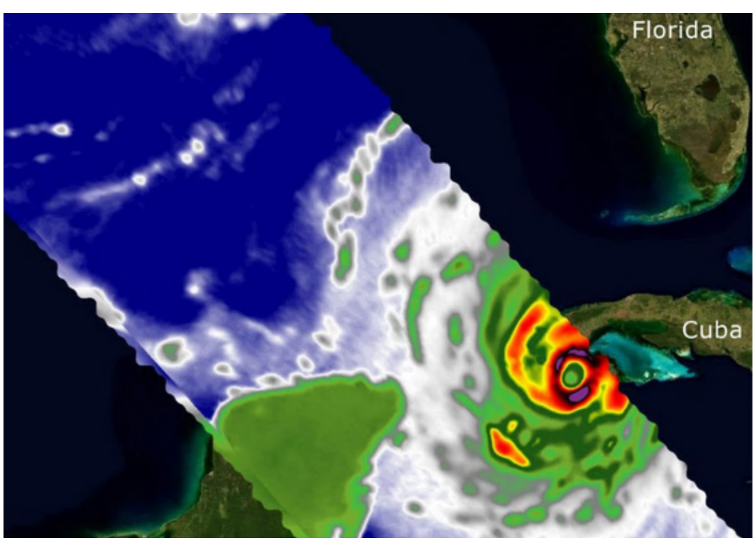

Figure: From aboard the International Space Station, two NASA-built instruments—the Compact Ocean Wind Vector Radiometer (COWVR) and Temporal Experiment for Storms and Tropical Systems (TEMPEST)—captured wind and water vapor data from Hurricane Ian as the storm neared Cuba on September 27, 2022, at 12:30 AM EDT. Ian's center is seen just off Cuba's southern coast, and the storm is shown covering the island with rain and wind. **Image Credit:** NASA/JPL

Visit the NASA Science Exhibit at the Hybrid 2022 AGU Fall Meeting

More than 25,000 attendees from over 100 countries will convene December 12–16 in Chicago, IL, and online everywhere to explore how *Science Leads the Future* at the 2022 Fall Meeting of the American Geophysical Union (AGU).

Please plan to visit the NASA Exhibit (#1937) in the exhibit hall, December 12–15. NASA also will host an interactive virtual exhibit on the NASA Virtual Event Platform, enabling online participants access to similar resources.

The focal point of NASA's exhibit in Chicago will be the nine-screen Hyperwall, where scientists will share science stories throughout the week so visitors can learn how NASA Science expands frontiers of science through investigations of Earth science, heliophysics, planetary science, and astrophysics.

The exhibit will feature more than twenty stations where visitors can learn about NASA Science missions, technology innovation, data resources, and how NASA is cultivating the next generation of data users and leaders. A wide range of NASA Science demonstrations, digital resources, printed materials, and tutorials on data tools and services will be shared.

A daily agenda will be posted on the Earth Observing System Project Science Office website—*eospso.nasa.gov*—in early December.

We hope to see you in Chicago!

Attendees explore the NASA Science exhibit during the 2021 Fall Meeting of the AGU in New Orleans, LA. **Photo credit:** NASA

Earth Science Meeting and Workshop Calendar

NASA Community

April 22–23, 2023
Earth Day
Washington, DC and Online

Global Science Community

January 8–12, 2023
American Meteorological Society (AMS) 103rd Annual Meeting
Denver, Colorado and Online
annual.ametsoc.org/index.cfm/2023

March 9–11, 2023
Commodity Classic
Orlando, Florida
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Article submissions, contributions to the meeting calendar, and other suggestions for content are welcomed. Contributions to the calendars should contain date, location (if meeting in person), URL, and point of contact if applicable. Also indicate if the meeting is *hybrid* (combining online and in person participation) or *virtual* (online only). Newsletter content is due on the weekday closest to the fifteenth of the month preceding the publication—e.g., December 15 for the January–February issue; February 15 for March–April, and so on.

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